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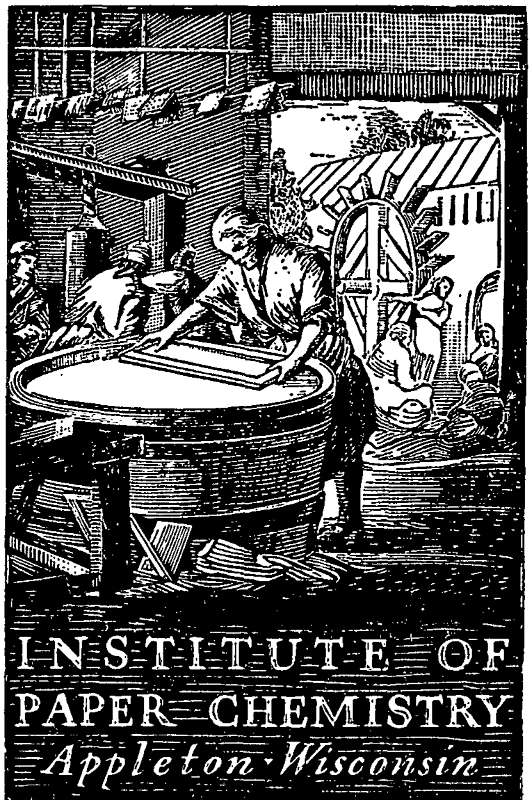


# EFFECT OF OPERATIONAL VARIABLES ON RUNNABILITY AND HIGH-LOW CORRUGATIONS

Project 2696-1

Report One

A Summary Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

January 15, 1968

GENERAL

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

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# EFFECT OF OPERATIONAL VARIABLES ON RUNNABILITY AND HIGH-LOW CORRUGATIONS

## SUMMARY

During the past year the Fourdrinier Kraft Board Institute, Inc., sponsored a study of the effect of various operational variables on a) runnability and b) the occurrence of high-low corrugations. For this purpose a number of semichemical, kraft, and bogus mediums were fabricated into A-flute single-faced board on the Institute's experimental corrugator under controlled conditions. Among the variables studied were 1) web tension, 2) steam shower pressure, 3) amount of medium preheat, 4) roll pressure, 5) roll parallelism, 6) angle of take-off, 7) web orientation, and 8) moisture content of the medium.

For each variable, the runnability was evaluated by progressively increasing the speed of the corrugator (maximum of 1000 ft./min.) until fracture of the medium occurred. To evaluate the effect of the variables on high-low corrugations, single-faced board samples were taken at various speed levels and evaluated to determine the average difference in height of consecutive flutes, flute height, etc. During the runs, measurements of draw factor and the temperature of the medium entering the nip were made.

A survey of the literature pertaining to runnability and high-low corrugations is included in the report.

For the conditions and materials evaluated in this study, the following conclusions may be drawn.

RUNNABILITY

## 1. Web Tension

As expected, the results indicated that increasing web tension significantly lowered the maximum runnability speed. On the average, runnability decreased by about 100 to 150 ft./min. per unit change in web tension. An increase in web tension resulted in a slight, but significant decrease in the draw factor at maximum runnability. The medium temperatures entering the corrugating labyrinth increased about 5 to 6% as tension increased from 0.25 to 2.0 lb./inch and the differences were statistically significant at the 0.01 level. There was some evidence that tension significantly affected medium thickness at the flute tip (flute tip caliper); however, the direction of the effect varied from medium-to-medium.

## 2. Steam Shower Pressure

In general, lower runnability speeds were obtained with no steam shower. However, increasing the shower pressure beyond the level normally used (14 p.s.i.) resulted in small or even no increases in runnability speed. Increasing shower pressures had no significant effect on the draw factor at maximum runnability but significantly increased the temperature of the medium entering the nip. Flute tip caliper decreased, on the average, as shower pressure increased and the differences were significant at the 0.01 level.

## 3. Amount of Medium Preheat

When the amount of "preheat" was increased from no wrap to half wrap on the preheater, runnability increased for each medium. The increases ranged from 100 to 175 ft./min. for those mediums which fractured at speeds less than 1000 ft./min.

Changing from half to full wrap on the preheater gave no to small increases in runnability and in one instance the runnability decreased. The analysis indicated that the amount of preheat significantly (0.05 level) affected runnability. As expected, the amount of preheat significantly (0.05 level) increased the temperature of the medium entering the nip. However, neither the draw factor nor flute tip caliper were significantly affected though in the latter case there was a significant interaction between amount of preheat and medium.

4. Corrugating Roll Pressure

For the conditions of this study, changes in roll pressure did not significantly affect the maximum runnability. Increasing roll pressures slightly increased the draw factor at maximum speed; however, the changes were not statistically significant at the 0.05 level. Flute tip calipers markedly decreased with increasing pressure and the changes were statistically significant at the 0.01 level.

5. Roll Parallelism

In general, the changes in roll parallelism employed in the study had little or no effect on runnability, draw factor, or flute tip caliper.

6. Medium Moisture Content

In a very limited comparison involving a semichemical medium made to moisture content levels of 1.7, 4.3, and 20.0 by one manufacturer, the runnability speeds were 450, 725, and 600 ft./min., respectively. These changes should be viewed with caution because normal manufacturing variations in furnish, paper machine operation, etc., could conceivably cause changes as great as those observed.

7. Angle of Take-off and Web Orientation

Varying the angle of take-off had little or no effect on runnability as would be expected. With regard to web orientation, somewhat lower runnabilities were obtained when the wire side of the medium was bonded to the single-face liner in two of the three comparisons.

8. Relationship Between the Physical Characteristics of the Medium and Runnability

A limited comparison of runnability with various physical characteristics of the medium, such as tensile, stretch, coefficient of friction, transverse tensile, transverse compression, etc., indicated that none of the properties by themselves, were well related to runnability.

HIGH-LOW CORRUGATIONS

1. Web Tension

The analysis indicated that increasing web tension may increase the tendency to form high-low corrugations but its effect is most evident at higher speeds. Also, increasing tension slightly decreased flute height.

2. Steam Shower Pressure

It appears that the use of steam showers generally decreases flute height differences — and hence, high-low corrugations — though the magnitude of the improvement depends on the particular medium. For the conditions of this study, it appears that the major improvement in high-lows occurs in going from no shower to the "normal" shower pressure of 14 p.s.i. Further increases in shower pressure seemed to have less effect. It was also noted that increasing shower pressure tended to slightly decrease flute height — particularly in going from no shower to 14 p.s.i. shower pressure.

3. Effect of Medium Preheat

For the conditions of this study, changing the amount of medium preheat did not significantly affect the average caliper differences and hence, the tendency to form high-low corrugations. However, in general, flute height increased with increasing amounts of medium preheat.

4. Effect of Roll Pressure

The results indicated that pressure, by itself, was not a highly significant factor in so far as high-low corrugations are concerned. However, a highly significant interaction between pressure and medium sample was observed and it appears that at low roll pressures certain mediums tend to exhibit higher caliper differences which might result in high-low corrugations. Increasing roll pressures also produced significantly higher flute heights.

5. Effect of Roll Parallelism

The results indicated that deviations from roll parallelism may tend to increase the tendency to form high-low corrugations; however, the magnitudes of the changes were not great enough to be highly significant for the conditions and materials of this study.

6. Effect of Angle of Take-off

While slightly lower caliper differences were obtained with a low angle of take-off as compared to a tangential or high angle of take-off, the differences between angles were not statistically significant at the 0.05 level in this limited study. Because of the variability in high-low measurements and the limited number of mediums involved, the analysis was apparently not sensitive enough to distinguish between effects in this case.

## 7. Web Orientation

On the average, changes in web orientation appeared to have little or no effect on either flute height or caliper differences and hence, high-low corrugations.

## 8. Effect of Moisture Content on High-Low Corrugations

Rolls manufactured to moisture contents of 1.7, 4.3, and 20.0% exhibited only small differences in their tendency to form high-low corrugations although the average flute height markedly decreased with increasing moisture content. Therefore, for these materials and experimental conditions it appears that roll moisture content may be varied over a wide range (so long as it is reasonably uniform) without materially affecting the tendency to form high-low corrugations. The results are very limited, of course, and should certainly be viewed with caution for this reason.

In contrast, when "wet streaks" were simulated by wetting portions of the medium before the preheater, the caliper differences in the wetted areas substantially increased relative to the untreated areas. This suggests that "wet streaks" may be expected to increase the tendency toward high-low corrugations.

## 9. Effect of Medium Properties

None of the properties of the medium taken individually were well related to the tendency to form high-low corrugations.

# INTRODUCTION

Corrugating is the basic operation in the manufacture of corrugated shipping containers. By means of this process three or more relatively flexible paperboard webs are converted into a relatively stiff, low-weight packaging material. Viewed in this way, the primary requirement of the corrugating operation is that it produces a product of satisfactory quality with respect to end-use performance at a cost competitive with alternative packaging materials.

The past decades have seen marked improvements in the corrugating process. Improvements in the quality of the fibrous components, adhesives, and in corrugating roll and machine design have resulted in increased operating speeds and economy of production. These have offset, in part, the trend to higher costs.

Because of the basic nature of the corrugating operation, the Fourdrinier Kraft Board Institute, Inc. has sponsored a number of studies at The Institute of Paper Chemistry into various aspects of the process. Two problems have been the subject of much attention, namely, runnability and "high-lows." Runnability is defined herein as the ability of the medium to withstand the stresses and strains of the corrugating operation without fracture and is measured in terms of the maximum corrugating speed at which the medium can be corrugated without fracture. The term "high-low" corrugations refers to the differences in height of consecutive flutes which, if too great, result in poor to no adhesion of the low flutes at the double-backer. The occurrence of either fracture or excessive high-lows may limit production speeds and increase waste with consequent increases in cost.

During the past year the FKBI has sponsored a study of the effect of various operational variables on (a) runnability, and (b) the occurrence of high-low corrugations. The results obtained in the study are summarized herein.

# GENERAL PROCEDURES

## MATERIALS

The following types of corrugating medium were to be procured for the study:

1. 26-Lb. semichemical representative of good runnability.
2. 26-Lb. kraft representative of good runnability.
3. 26-Lb. bogus representative of good runnability.
4. 26-Lb. semichemical known to produce high-lows.
5. 26-Lb. kraft known to produce high-lows.
6. 26-Lb. bogus known to produce high-lows.
7. 26-Lb. semichemical manufactured at several levels of moisture content.
8. 33-Lb. semichemical (run-of-mill).

The physical characteristics of the mediums selected for the study are summarized in Tables I and II. Test procedures employed are described in the following section.

All mediums were combined with 42-lb. kraft liner. The basis weight and caliper of the linerboard rolls are summarized in Table III.

## CORRUGATOR VARIABLES AND FABRICATION

### Operational Variables Studied

The following operational variables were studied:

1. Corrugating speed: 150 to 1000 f.p.m. maximum.
2. Web tension, three levels: 0.25, 1, and 2 lb./in.

TABLE I

PHYSICAL CHARACTERISTICS OF CORRUGATING MEDIUM SAMPLES

| No. | Type of Medium | Roll No. | Moisture Content,[d] % | Basis Weight, lb./M ft.$^2$ | Caliper, pt. | Concora Flat Crush, p.s.i. | Modified Ring Compression,[c] lb./in. | Tensile,[c] lb./in. | Stretch, %[c] | Impulse, mNs[c] | Coeff. of Friction[c] 73°F. Felt Side | Coeff. of Friction[c] 73°F. Wire Side | Coeff. of Friction[c] 300°F. Felt Side | Coeff. of Friction[c] 300°F. Wire Side | Z-Direction Tensile, kg./cm.$^2$ | IGT,[bc] Kp.cm./sec. Felt Side | IGT,[bc] Kp.cm./sec. Wire Side |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 26-Lb. semichemical | 28 | 6.3 | 27.0 | 9.9 | 36.0 | 18.2 | 36.7 | 1.2 | 7.5 | 0.22 | 0.24 | 0.16 | 0.14 | 13.2 | 78 | 68 |
| | | 29 | 5.6 | 26.9 | 9.9 | 35.5 | 17.9 | 35.8 | 1.2 | 6.4 | .25 | .24 | .16 | .13 | 13.2 | 72 | 76 |
| | | 30 | 6.1 | 27.1 | 9.9 | 35.2 | 18.3 | 36.9 | 1.3 | 7.5 | .22 | .23 | .13 | .15 | 12.0 | 79 | 51 |
| | | Av. | 6.0 | 27.0 | 9.9 | 35.6 | 18.1 | 36.5 | 1.2 | 7.1 | .23 | .24 | .15 | .14 | 12.8 | 76 | 65 |
| 2 | 26-Lb. semichemical | 59 | 9.8 | 26.5 | 10.1 | 35.7 | 17.1 | 48.6 | 1.2 | 8.8 | 0.26 | 0.25 | 0.17 | 0.13 | 10.8 | 76 | 45 |
| | | 60 | 8.0 | 26.4 | 10.2 | 35.8 | 17.1 | 49.5 | 1.2 | 8.2 | .24 | .25 | .17 | .14 | 11.0 | 70 | 69 |
| | | Av. | 9.9 | 26.4 | 10.2 | 35.8 | 17.1 | 49.0 | 1.2 | 8.5 | .25 | .25 | .17 | .14 | 10.9 | 73 | 57 |
| 3 | 26-Lb. kraft | 46 | 5.9 | 27.4 | 8.9 | 29.8 | 18.1 | 60.0 | 1.7 | 14.8 | 0.26 | 0.23 | 0.15 | 0.11 | 7.8 | 66 | 88 |
| | | 47 | 4.5 | 27.4 | 8.7 | 30.1 | 18.2 | 59.6 | 1.7 | 16.7 | .25 | .22 | .15 | .10 | 7.8 | 65 | 78 |
| | | Av. | 5.2 | 27.4 | 8.8 | 30.0 | 18.2 | 59.8 | 1.7 | 15.8 | .26 | .22 | .15 | .10 | 7.8 | 66 | 83 |
| 4 | 26-Lb. kraft | 44 | 4.2 | 28.9 | 9.9 | 45.6 | 20.6 | 68.5 | 2.3 | 20.8 | 0.26 | 0.24 | 0.15 | 0.13 | 9.6 | 76 | 81 |
| | | 45 | 4.0 | 28.7 | 9.8 | 44.9 | 20.9 | 66.7 | 2.2 | 21.2 | .24 | .24 | .14 | .13 | 9.1 | 104 | 94 |
| | | 146 | 5.6 | 27.8 | 9.7 | 37.9 | 18.9 | 63.8 | 2.0 | 16.5 | .24 | .23 | .14 | .14 | 8.0 | 76 | 47 |
| | | 147 | 5.3 | 28.7 | 9.5 | 41.5 | 21.1 | 69.9 | 2.1 | 17.2 | .24 | .22 | .13 | .14 | 8.3 | 98 | 92 |
| | | Av. | 4.8 | 28.5 | 9.7 | 42.5 | 20.4 | 67.2 | 2.2 | 18.9 | .24 | .23 | .14 | .14 | 8.8 | 88 | 78 |
| 5 | 26-Lb. bogus | 84 | 6.5 | 26.8 | 9.9 | 35.6 | 17.4 | 59.6 | 1.8 | 17.5 | 0.25 | 0.25 | 0.17 | 0.13 | 9.0 | 30 | 68 |
| | | 85 | 6.0 | 26.5 | 9.8 | 35.7 | 17.2 | 60.1 | 1.8 | 15.1 | .24 | .24 | .16 | .14 | 9.4 | 36 | 72 |
| | | Av. | 6.2 | 26.6 | 9.8 | 35.6 | 17.3 | 59.8 | 1.8 | 16.3 | .24 | .24 | .16 | .14 | 9.2 | 33 | 70 |
| 6 | 26-Lb. bogus | 88 | 6.1 | 26.8 | 9.7 | 38.1 | 17.5 | 60.6 | 1.9 | 18.7 | 0.24 | 0.25 | 0.16 | 0.14 | 10.0 | 26 | 24 |
| | | 89 | 5.6 | 27.1 | 9.3 | 34.2 | 17.8 | 60.2 | 1.9 | 17.9 | .24 | .24 | .15 | .13 | 8.8 | 50 | 30 |
| | | 90 | 6.3 | 27.0 | 9.3 | 36.4 | 17.6 | 59.8 | 2.0 | 15.7 | .24 | .21 | .13 | .15 | 9.9 | 29 | 27 |
| | | Av. | 6.0 | 27.0 | 9.4 | 36.2 | 17.6 | 60.2 | 1.9 | 17.4 | .24 | .23 | .15 | .14 | 9.6 | 35 | 27 |

Please see end of table for footnote.

TABLE I (Contd)

PHYSICAL CHARACTERISTICS OF CORRUGATING MEDIUM SAMPLES

| No. | Type of Medium | Roll No. | Moisture Content,[d] % | Basis Weight, lb./M ft.$^2$ | Caliper, pt. | Concora Flat Crush, p.s.i. | Modified Ring Compression, lb./in.[c] | Tensile, lb./in.[c] | Stretch, %[c] | Impulse, mNs[c] | Coeff. of Friction[c] 73°F. Felt Side | 73°F. Wire Side | 300°F. Felt Side | 300°F. Wire Side | Z-Direction Tensile, kg./cm.$^2$ | IGT, kp.cm./sec.[bc] Felt Side | IGT Wire Side |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 33-Lb. semichemical | 148 | 6.9 | 32.7 | 12.0 | 49.9 | 24.2 | 59.8 | 1.7 | 15.4 | 0.25 | 0.22 | 0.16 | 0.15 | 9.8 | 118 | 92 |
| | | 149 | 7.1 | 32.5 | 11.8 | 48.9 | 23.7 | 60.8 | 1.8 | 15.3 | .22 | .23 | .18 | .15 | 9.8 | 124 | 92 |
| | | Av. | 7.0 | 32.6 | 11.9 | 49.4 | 24.0 | 60.3 | 1.8 | 15.4 | .24 | .22 | .17 | .15 | 9.8 | 121 | 92 |
| 8[a] | 26-Lb. semichemical | 175 | 1.7 | 26.0 | 10.5 | 29.4 | 17.0 | 38.7 | 1.0 | 7.6 | 0.22 | 0.25 | 0.13 | 0.16 | 8.1 | 54 | 74 |
| 9[a] | 26-Lb. semichemical | 173 | 4.3 | 27.0 | 10.3 | 35.2 | 18.3 | 43.7 | 1.2 | 8.0 | 0.23 | 0.25 | 0.14 | 0.16 | 10.0 | 98 | 99 |
| 10[a] | 26-Lb. semichemical | 174 | 20.0 | 28.6 | 10.0 | 34.2 | 17.3 | 41.3 | 1.6 | 9.3 | 0.22 | 0.24 | 0.13 | 0.15 | 8.3 | 60 | 84 |

[a]Manufactured by one mill to three moisture content levels.

[b]Fiber pick end point.

[c]Machine-direction orientation.

[d]Ovendry basis.

Note: Roll averages are in most cases the average of tests on samples taken from start, middle and end of roll.

TABLE II

TRANSVERSE COMPRESSION CHARACTERISTICS OF CORRUGATING MEDIUM

| No. | Medium Identification: Type | Medium Identification: Roll No. | Compression Pressure, p.s.i. | 73°F. Compression Temperature: Caliper, pt. | 73°F. Compression Temperature: Loss in Caliper, % | 300°F. Compression Temperature: Caliper, pt. | 300°F. Compression Temperature: Loss in Caliper, % |
|---|---|---|---|---|---|---|---|
| 1 | 26-Lb. semichemical | S028,S029,S030 | 7[a] | 9.30 | -- | 8.66 | -- |
| | | | 1000 | 6.65 | - 28.5 | 5.72 | - 33.9 |
| | | | 2000 | 6.04 | - 35.1 | 5.11 | - 41.0 |
| | | | 5000 | 5.20 | - 44.1 | 4.41 | - 49.1 |
| | | | 8620 | 4.76 | - 48.8 | 4.00 | - 53.8 |
| | | | 7[b] | 5.01 | - 46.1 | 4.40 | - 49.2 |
| 2 | 26-Lb. semichemical | S059,S060 | 7[a] | 9.59 | -- | 9.19 | -- |
| | | | 1000 | 6.29 | - 34.4 | 5.36 | - 41.7 |
| | | | 2000 | 5.80 | - 39.5 | 4.85 | - 47.2 |
| | | | 5000 | 5.47 | - 43.0 | 4.28 | - 53.4 |
| | | | 8620 | 4.89 | - 49.0 | 4.01 | - 56.4 |
| | | | 7[b] | 4.99 | - 48.0 | 4.77 | - 48.1 |
| 3 | 26-Lb. kraft | S046,S047 | 7[a] | 8.62 | -- | 8.44 | -- |
| | | | 1000 | 6.49 | - 24.7 | 5.82 | - 31.0 |
| | | | 2000 | 5.95 | - 31.0 | 5.35 | - 36.6 |
| | | | 5000 | 5.30 | - 38.5 | 4.68 | - 44.5 |
| | | | 8620 | 4.98 | - 42.2 | 4.45 | - 47.3 |
| | | | 7[b] | -- | -- | 4.91 | - 41.8 |
| 4 | 26-Lb. kraft | S144,S145,S146 and S147 | 7[a] | 9.18 | -- | 8.97 | -- |
| | | | 1000 | 6.57 | - 28.4 | 5.94 | - 33.8 |
| | | | 2000 | 5.83 | - 36.5 | 5.26 | - 41.4 |
| | | | 5000 | 5.00 | - 45.5 | 4.56 | - 49.2 |
| | | | 8620 | 4.61 | - 49.8 | 4.14 | - 53.8 |
| | | | 7[b] | 4.88 | - 46.8 | 4.66 | - 48.0 |
| 5 | 26-Lb. bogus | S084,S085 | 7[a] | 9.44 | -- | 8.89 | -- |
| | | | 1000 | 6.24 | - 33.9 | 5.46 | - 38.6 |
| | | | 2000 | 5.58 | - 40.9 | 4.88 | - 45.1 |
| | | | 5000 | 4.80 | - 49.2 | 4.19 | - 52.9 |
| | | | 8620 | 4.48 | - 52.5 | 3.82 | - 57.0 |
| | | | 7[b] | 4.63 | - 51.0 | 4.41 | - 50.4 |

Please see end of table for footnote.

TABLE II (Contd)

TRANSVERSE COMPRESSION CHARACTERISTICS OF CORRUGATING MEDIUM

| No. | Medium Identification: Type | Roll No. | Compression Pressure, p.s.i. | 73°F. Compression Temperature: Caliper, pt. | 73°F.: Loss in Caliper, % | 300°F. Compression Temperature: Caliper, pt. | 300°F.: Loss in Caliper, % |
|---|---|---|---|---|---|---|---|
| 6 | 26-Lb. bogus | 5088, 5089, 5090 | 7[a] | 8.62 | -- | 8.21 | -- |
| | | | 1000 | 5.83 | - 32.4 | 5.49 | - 33.1 |
| | | | 2000 | 5.22 | - 39.4 | 4.93 | - 40.0 |
| | | | 5000 | 4.49 | - 47.9 | 4.31 | - 47.5 |
| | | | 8620 | 4.12 | - 52.2 | 3.94 | - 52.0 |
| | | | 7[b] | 4.46 | - 48.3 | 4.30 | - 47.6 |
| 7 | 33-Lb. semichemical | 5148, 5149 | 7[a] | 11.28 | -- | 11.06 | -- |
| | | | 1000 | 7.86 | - 30.3 | 7.48 | - 32.4 |
| | | | 2000 | 7.02 | - 37.8 | 6.68 | - 39.6 |
| | | | 5000 | 6.00 | - 46.8 | 5.70 | - 48.5 |
| | | | 8620 | 5.50 | - 51.2 | 5.24 | - 52.6 |
| | | | 7[b] | 5.97 | - 47.1 | 6.17 | - 44.2 |
| 8 | 26-Lb. semichemical | 5175 | 7[a] | 9.37 | -- | 9.30 | -- |
| | | | 1000 | 7.14 | - 23.8 | 6.05 | - 34.9 |
| | | | 2000 | 6.43 | - 31.4 | 5.36 | - 42.4 |
| | | | 5000 | 5.45 | - 41.8 | 4.66 | - 49.9 |
| | | | 8620 | 5.00 | - 46.6 | 4.14 | - 55.5 |
| | | | 7[b] | 5.46 | - 41.7 | 5.02 | - 46.0 |
| 9 | 26-Lb. semichemical | 5173 | 7[a] | 9.54 | -- | 9.22 | -- |
| | | | 1000 | 6.84 | - 28.3 | 6.11 | - 33.7 |
| | | | 2000 | 6.13 | - 35.7 | 5.44 | - 41.0 |
| | | | 5000 | 5.26 | - 44.9 | 4.78 | - 48.2 |
| | | | 8620 | 4.79 | - 49.8 | 4.26 | - 53.8 |
| | | | 7[b] | 5.46 | - 42.8 | 5.04 | - 45.3 |
| 10 | 26-Lb. semichemical | 5174 | 7[a] | 9.59 | -- | 8.60 | -- |
| | | | 1000 | 7.34 | - 23.5 | 6.10 | 29.1 |
| | | | 2000 | 6.74 | - 29.7 | 5.56 | 35.3 |
| | | | 5000 | 5.85 | - 39.0 | 4.98 | 42.1 |
| | | | 8620 | 5.34 | - 44.3 | 4.48 | 47.9 |
| | | | 7[b] | 5.96 | - 37.9 | 5.46 | 36.5 |

[a] Initial pressure.

[b] After unloading to initial pressure.

TABLE III

PHYSICAL CHARACTERISTICS OF LINERBOARD USED IN
ALL FABRICATION TRIALS

| Liner Roll No. | Basis Weight, lb./M ft.² Start | End | Av. | Caliper, pt. Start | End | Av. |
|---|---|---|---|---|---|---|
| 9 | 43.1 | 43.3 | 43.2 | 13.1 | 12.9 | 13.0 |
| 10 | 43.2 | 43.5 | 43.4 | 12.9 | 13.1 | 13.0 |
| 13 | 43.5 | 43.5 | 43.5 | 13.1 | 13.0 | 13.0 |
| 16 | 43.5 | 43.5 | 43.5 | 13.2 | 13.1 | 13.2 |
| 17 | 43.5 | 43.3 | 43.4 | 13.1 | 12.9 | 13.0 |
| 15 | 43.5 | 44.0 | 43.8 | 13.3 | 13.2 | 13.2 |
| 52 | 42.4 | 42.7 | 42.6 | 13.5 | 13.1 | 13.3 |
| 20 | 43.7 | 43.2 | 43.4 | 13.2 | 13.0 | 13.1 |
| 56 | 42.3 | 42.5 | 42.4 | 13.2 | 13.1 | 13.2 |
| 60 | 42.1 | 42.3 | 42.2 | 12.9 | 13.2 | 13.0 |
| 71 | 42.9 | 43.0 | 43.0 | 13.2 | 13.1 | 13.2 |
| 76 | 42.4 | 42.7 | 42.6 | 13.1 | 12.8 | 13.0 |
| 83 | 43.1 | 43.0 | 43.0 | 13.3 | 13.4 | 13.4 |
| 126 | 44.3 | 43.3 | 43.8 | 13.3 | 13.4 | 13.4 |
| 134 | 43.5 | 44.3 | 43.9 | 13.1 | 13.4 | 13.2 |
| 136 | 42.2 | 41.8 | 42.0 | 13.6 | 13.0 | 13.3 |
| 138 | 43.5 | 43.8 | 43.6 | 13.4 | 13.4 | 13.4 |

3. Moisture content:

   a. Three levels, 1.7, 4.3, and 20.0%.

   b. Uniformity: Added wet streak on each of the three medium rolls manufactured to different moisture contents.

4. Parallelism of corrugating rolls: Three levels.

5. Roll pressure: Three levels – 187, 327, and 513 lb./in.

6. Amount of steam at shower: Three levels – None (0 p.s.i.), regular (14 p.s.i.), heavy (28 p.s.i.).

7. Effect of web orientation: Wire up and wire down (primarily of interest relative to its effect on runnability).

8. Angle of take-off: Tangential to pressure roll nip, 15° high and 15° low (primarily of interest relative to its effect on high-low corrugations).

9. Preheater: Three levels – none, one-half, and full wrap. At one-half and full wrap, the preheater steam shower was employed using a steam pressure of 1 p.s.i.

In addition to the above, it was planned to investigate the effect of temperature at levels up to 450 or 500°F. For this purpose a roll heating system employing electrically heated Dowtherm as the heat transfer medium was procured and installed. Trials of the equipment indicated that the rate of heat transfer for the system employed was insufficient to maintain the desired high roll temperature levels. For this reason, this approach was abandoned and all runs were made at the standard operating temperature – approximately 350°F.

## Fabrication Procedure

The effect of each variable was determined by means of experimental fabrication runs on the Institute's corrugator using a standard 42-lb. kraft liner and starch adhesive. All runs were made using A-flute Langston corrugating rolls. Each level of a variable was studied by progressively increasing the speed of the corrugator and noting the maximum speed at which the selected medium corrugated satisfactorily. For this purpose the speed was increased in 150 f.p.m. increments from 150 f.p.m. to 900 f.p.m. and at the maximum speed of 1000 f.p.m. Samples of the single-faced board at each speed were examined for evidence of flute fracture. The speed levels at which fractures were and were not evident were noted and additional runs were made in which the speed was varied in 25 f.p.m. increments between the two levels. These board samples were then examined to determine the highest speed (runnability) at which no flute fractures occurred. Samples of the single-faced board at the various speed levels were set aside for subsequent evaluation of high-low corrugations. During each fabrication run the temperature of the corrugating medium at the entrance to the corrugating nip was measured using an Ircon Model 700 radiation thermometer.

The fabrication runs were carried out using the following standard operating conditions with the exception of the particular variable under study:

1. Medium web tension: 1 lb./in. of medium width.
2. Steam showers: 14 p.s.i.
3. Medium preheat: Full preheater wrap plus 1 p.s.i. steam shower.
4. Web orientation: Felt side bonded to single-face liner.
5. Corrugator roll pressure: 327 lb./in. of medium width.
6. Angle of take-off of single-faced board: Tangential.
7. Glue roll settings:
    a) Transfer roll to lower corrugating roll
        (1) Clearance: 0.012 inch
        (2) Speed ratio: 95%

b) Doctor roll to transfer roll

(1) Clearance: 0.0095 inch

(2) Speed ratio: 95%

8. Finger clearance: 0.015 in. (no relief type).

9. Adhesive: Stein-Hall formulation made daily

a) Viscosity: 32 ± 1 sec. at 100°F.

b) Gel point: 138 ± 2°F.

c) pH: 12.0 ± 0.2

EVALUATION OF COMPONENTS AND SINGLE-FACED BOARD

Conditioning

All corrugating medium, liner, and single-faced board samples were conditioned for at least 16 hours at less than 35% R.H. and 73°F., and conditioned for at least 48 hours at 50 ± 2% R.H. and 73°F. prior to testing.

Tests on Corrugating Medium

The tests made and the number of tests for each roll of medium are summarized in Table IV. TAPPI methods were followed for the weight, caliper, moisture content, Concora, tensile and stretch tests, except as noted in Table IV. Brief descriptions of the procedures employed for the remaining tests are discussed below:

The Impulse tester was described in an article by Andersson (1) and was devised for the purpose of evaluating the tensile characteristics of sack paper at high test rates. Basically, the instrument consists of a pendulum to one end of which a specimen is clamped. The other end of the specimen is clamped in a movable clamp which rides on a track. A revolving wheel strikes the movable clamp driving it

TABLE IV

NUMBER OF MEDIUM TESTS

| | Test | No. of Tests per Sample | Total No. of Tests per Medium Roll | Roll Sampling Locations |
|---|---|---|---|---|
| 1 | Basis weight | 1000 in.$^2$ | 3000 in.$^2$ | Start, middle, and end |
| 2 | Caliper | 10 | 30 | Start, middle, and end |
| 3 | Moisture content[a] | 2 | 6 | Start, middle, and end |
| 4 | Concora[b] | 5 | 15 | Start, middle, and end |
| 5 | Modified ring compression (M.D.)[d] | 5 | 15 | Start, middle, and end |
| 6 | Tensile (M.D.)[c] | 5 | 15 | Start, middle, and end |
| 7 | Stretch (M.D.)[c] | 5 | 15 | Start, middle, and end |
| 8 | Impulse (M.D.) | 5 | 10 | Start and end |
| 9 | z-Direction tensile | 5 | 10 | Start and end |
| 10 | IGT pick test | 5 | 10 | Start and end |
| 11 | Kinetic coefficient of friction | 5 | 5 | End only |
| 12 | Transverse compression | 1 | 2 | Start and end |

[a]Results expressed on ovendry basis.

[b]Conditioned for 15-45 minutes at 50% R.H. after fluting prior to testing.

[c]6-Inch span, 0.2 inch per minute.

[d]2-Inch length, wax-dipped edges, specimen ends joined with contact cement; see also Compression Report 78, June 24, 1963.

down the track. As the clamp moves, an impulse (integral of force operating over the time period) is transmitted through the specimen to the pendulum. The movement of the pendulum is proportional to the impulse transmitted through the specimen before failure and is expressed in milli-Newton seconds. The specimen width is 10 mm. and the span is 100 mm.

The z-direction tensile test is similar in principle to a number of other tests devised to measure the transverse tensile or bond strength (this same principle is used in many ply separation tests) of paper and paperboard. Essentially, the test involves adhering the specimen between two steel cylinders and measuring the maximum force required to separate the specimen. A complete description of the test procedure may be found in an article by Wink and Van Eperen (2).

Pick resistance tests were made with the IGT printability tester using a 1-cm. wide disk, 25 kg./cm. nip load, and 10 nm. film of 1400 poise viscosity polybutene. The drawsheet of a 3-ply newspaper press blanket was mounted in the specimen sector as backing. After applying the film to the disk with a doctor blade device and running the disk against the specimen on the pendulum sector, the specimen was examined for pick failures, evidenced by fiber lifting. The location of the first sign of continuous failure was taken as the end point. The pendulum velocity at that point is multiplied by the polybutene's viscosity to give the velocity-viscosity product in kp.cm./sec. The larger the value, the more resistant the medium is to picking. Used in this way the IGT test is a measure of internal sheet bonding and is somewhat similar in purpose to the z-direction tensile test; however, the two tests apparently measure somewhat different sheet characteristics and may not show high correlation.

The frictional properties of the medium (medium vs. chrome-plated steel) surface were determined using a modified version of a tester developed at the Institute.

A description of the original instrument may be found in Reference (3). A test was performed by placing a strip of medium on a Teflon-covered plane, placing a chrome-plated steel block (weight of block corresponds to 0.68 p.s.i. pressure on specimen) on the top surface of the specimen and pulling the specimen from under the chromed block at a fixed rate of speed (87 in./min.). The chromed block is attached by means of a flexible cable to a cantilever beam which measures the frictional force. Tests were made at slider temperatures of 73°F. and 300°F. The latter was obtained by heating the slider to 300°F. on a hot plate between each test.

The transverse compression characteristics of the medium were measured by using a special compression jig to apply compression force in the thickness direction of the sheet over an effective specimen area of 2.90 in.$^2$. Load-deformation curves were obtained using a test rate of 30,000 lb./min. up to a total load of 25,000 lb. Tests were made at both 73°F. and 300°F. using the same procedure except that in the hot tests a pair of heating elements were inserted in the lower anvil of the jig to heat the press to 300°F.

Tests on Single-Faced Board

The following tests were made on the single-faced board samples representing a given medium and corrugating condition:

1. Individual flute caliper.
2. Average caliper difference of consecutive flutes (calculated from 1, above).
3. Maximum difference in height of consecutive flutes (calculated from 1, above).
4. Number of differences in height of consecutive flutes in the following ranges: 0-3.0, 0-4.0, and 0-5.0 pt. (calculated from 1, above).

5. Single-faced board caliper.
6. Flute tip caliper of the corrugated medium at maximum runnability.

The procedures used are described briefly below:

Individual Flute Caliper

From each sample of single-faced board, ten 5 in.$^2$ circular specimens were cut at approximately 5-ft. intervals avoiding folds, creases, etc. A special caliper was used to measure the heights of five consecutive flutes on each specimen to the nearest 0.0001 inch. The force on the spindle of the dial gage was 100 grams and the diameter of the caliper foot was 3/8 inch.

The average individual flute caliper was calculated from the average of the 50 height measurements. The average difference in height of consecutive flutes was calculated by taking the absolute difference between consecutive flutes (four differences per 5-flute height measurements on a given specimen), summing the differences for the ten specimens and dividing by the total number of differences (40).

In addition, the number of individual differences in height of consecutive flutes which fell within three ranges — 0 to 3.0, 0 to 4.0, and 0 to 5.0 points — were counted to obtain a measure of the distribution. The ranges were arbitrarily selected to encompass a commercially practical range.

Single-Faced Board Caliper

The circular 5 in.$^2$ specimens were placed on the lower anvil of a Cady micrometer caliper. A 0.020-in. feeler gage was laid across the flute tips and the foot of the caliper was gently lowered into contact with the feeler gage. The indicated caliper reading minus the thickness of the feeler gage was recorded as the single-faced board caliper. Ten determinations were made.

Flute Tip Caliper of the Corrugated Medium at Maximum Runnability

Five of the circular 5-in.$^2$ specimens used for the individual flute height measurements were selected. Two consecutive flute tips were cut from each specimen containing at least one-half of the adjacent side walls on either side of the tip. Each flute tip was then placed over a 0.080-in. diameter anvil and positioned so the center of the tip was in line with a 1/4-inch diameter foot attached to a sensitive dial indicator. The caliper was read to the nearest 0.1 point (0.0001 inch) and ten determinations were made.

# REVIEW OF LITERATURE ON RUNNABILITY

## EFFECT OF OPERATIONAL VARIABLES

### Corrugating Speed

Runnability is generally measured in terms of either the maximum speed with minimum tension or a given level of speed with specified tension at which a medium can be corrugated without fracturing. With either of these methods there is a limiting speed and tension beyond which a given medium will fracture. Previous studies (4,5) have mentioned that corrugating speed enters directly into several of the types of stress and strain to which a medium is subjected during corrugating. McKee (6) has shown that runnability is inversely related to web tension.

Corrugating speed may also determine the relative amounts of bending and shear strains imposed on the medium during flute formation. The apportionment between these two strains may depend on the corrugating speed because the strains vary differently with temperature and moisture content which, in turn, vary with corrugating speed. Thus, it is possible that one of these strains may exceed the allowable strain of the medium at a high speed, whereas it may not at a low speed. Specifically, it appears likely that the increased rate of straining accompanying increases in corrugating speed will decrease the stretch and allowable shear strain of a medium (7,8). However, both decreased temperature and increased moisture content of a medium corrugated at high speed may be expected to increase the allowable strain in a medium. This latter effect may tend to compensate for the reduction in allowable strain associated with the higher rate of straining at higher corrugating speeds. However, the net effects of these interacting phenomena at higher corrugating speeds on the safe levels of strain which a medium can sustain are not clear at this time.

In a study made at the Institute (9) of the dynamics of the upper corrugating roll, it was found that there was a trend for the molding force to decrease at the tip of the flutes and to increase at the side walls with increasing corrugating speed. From this trend it may be inferred that the molding of the A-flute arches became less complete and the side walls were more severely stressed as the corrugating speed increased.

In another study at the Institute (10), rolls submitted for evaluation in the base-line study on medium during Sept., Oct., Nov., and Dec., 1958, and Jan., Feb., and March, 1959 were evaluated for runnability and those rolls that corrugated satisfactorily at 600 f.p.m. with minimum, 1/2, 1, or 1-1/2 lb./in. tension were further evaluated to determine the maximum speed at which each roll could be run with minimum tension (maximum speed was 1000 ft./min.). The results of this evaluation are summarized in Table V. One conclusion that may be reached from these results is that the speed at which a given medium can be satisfactorily fabricated is affected significantly by transport tension and can be increased appreciably by reducing transport tension.

Another variable influenced by corrugating speed is the draw factor, the ratio of medium footage to linerboard footage per foot of single-faced board. A study (11) carried out at the Institute has shown that the draw factor generally increases as medium runnability increases. This behavior implies that high runnability mediums can be molded more readily and completely because of a favorable combination of physical properties.

TABLE V

MAXIMUM SPEED (F.P.M.) AT MINIMUM TENSION VERSUS
MAXIMUM TENSION AT 600 F.P.M.

| Date | Max. Tension, lb./in., at 600 f.p.m. | | | |
|---|---|---|---|---|
| | Min. | 1/2 | 1 | 1-1/2 |
| | Max. Corrugating Speed, f.p.m., at minimum tension | | | |
| Sept., 1958 | 730 | 919 | 944 | 994 |
| Oct., 1958 | 673 | 908 | 966 | 993 |
| Nov., 1958 | 694 | 855 | 957 | 989 |
| Dec., 1958 | 714 | 858 | 850 | 994 |
| Jan., 1959 | 675 | 808 | 906 | 993 |
| Feb., 1959 | 750 | 850 | 1000 | 995 |
| March, 1959 | 690 | 891 | 990 | 993 |
| Av. | 704 | 870 | 945 | 993 |

Note: Because maximum speeds of 1000 ft./min. were included in averages, the speed averages at the higher tension values underestimate the potential operating speed at minimum tension.

It should be mentioned that some operational factors on today's single-facers limit the speed at which mediums with excellent potential for high-speed fabrication can be corrugated. Wood (12), for example, has noted that these potential corrugating speeds cannot be utilized because of limitations in our present adhesives. He forecasts future speeds of up to 1500 ft./min. when new adhesive systems utilizing thermoplastic resins in emulsion and hot-melt form are available.

## Web Tension

One of the major factors limiting runnability speed is web tension. Increasing web tension markedly lowers runnability speed (6, 10). A comprehensive analysis of the tension forces induced in the web in the corrugating process was made in Reference (4). The analysis indicated that prior to the point where the medium contacts the top corrugating roll, the average transport tension is primarily dependent on the force required to unwind the parent roll, overcome friction between medium and preheater drum, and overcome friction at the reel brake. Tension forces required to (a) drive the idler rolls, (b) resist centrifugal effects at idler rolls or other curved surfaces, and (c) support the web weight in free spans between idler rolls, were of minor consequence — at least for the Institute's corrugator.

The same analysis indicated that after the medium contacts the top corrugating roll (Region BD, Fig. 1), the frictional forces further increase the tension in the web. This occurs because the medium travels faster than the peripheral speed of the tooth tips of the corrugating rolls. Each tooth tip in contact with the medium exerts a force of friction on the medium which opposes the draw, resulting in an increase in transport tension in the medium on the leading side of the tooth. The increments of tension at each tooth tip accumulate, with the result that the transport tension substantially increases as the center of the labyrinth is approached.

When the medium reaches Point C of Fig. 2, it is noted in Reference (4) that the medium is impacted by the first tooth of the bottom roll in the labyrinth. This causes it to deflect laterally and initiate the flute forming stage. With proper instrumentation this impact tension may be sensed by a tensiometer located ahead of the top corrugating roll.

In the labyrinth (Region CD, Fig. 2), the medium is formed into the fluted shape and severe deformations are induced in the medium. The analysis in Reference (4) indicates, qualitatively, that high bending and shear strains may be induced in the medium in this stage. As a result of bending the tensile strains are higher in the outside plies of the flute tip.

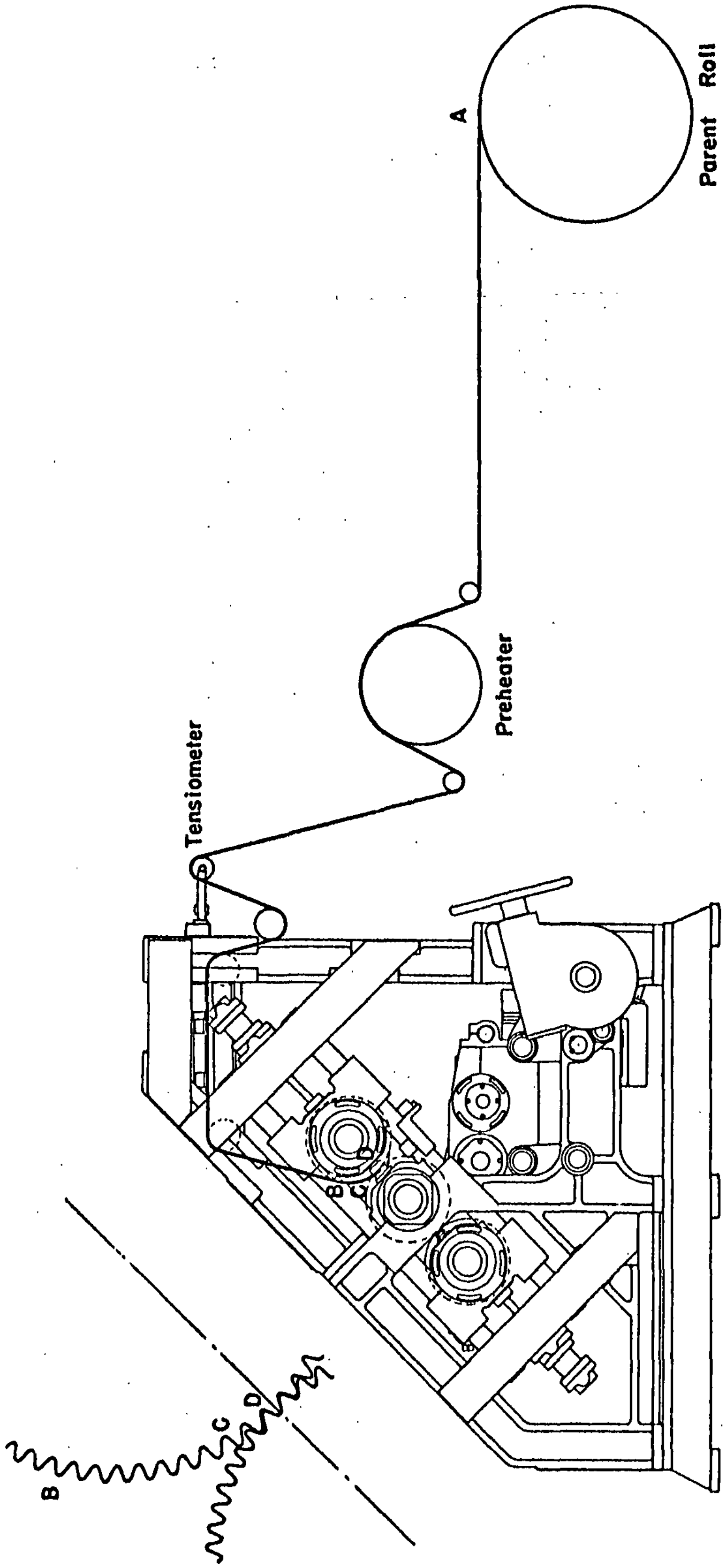


Figure 1. Path of Medium Through Experimental Corrugator

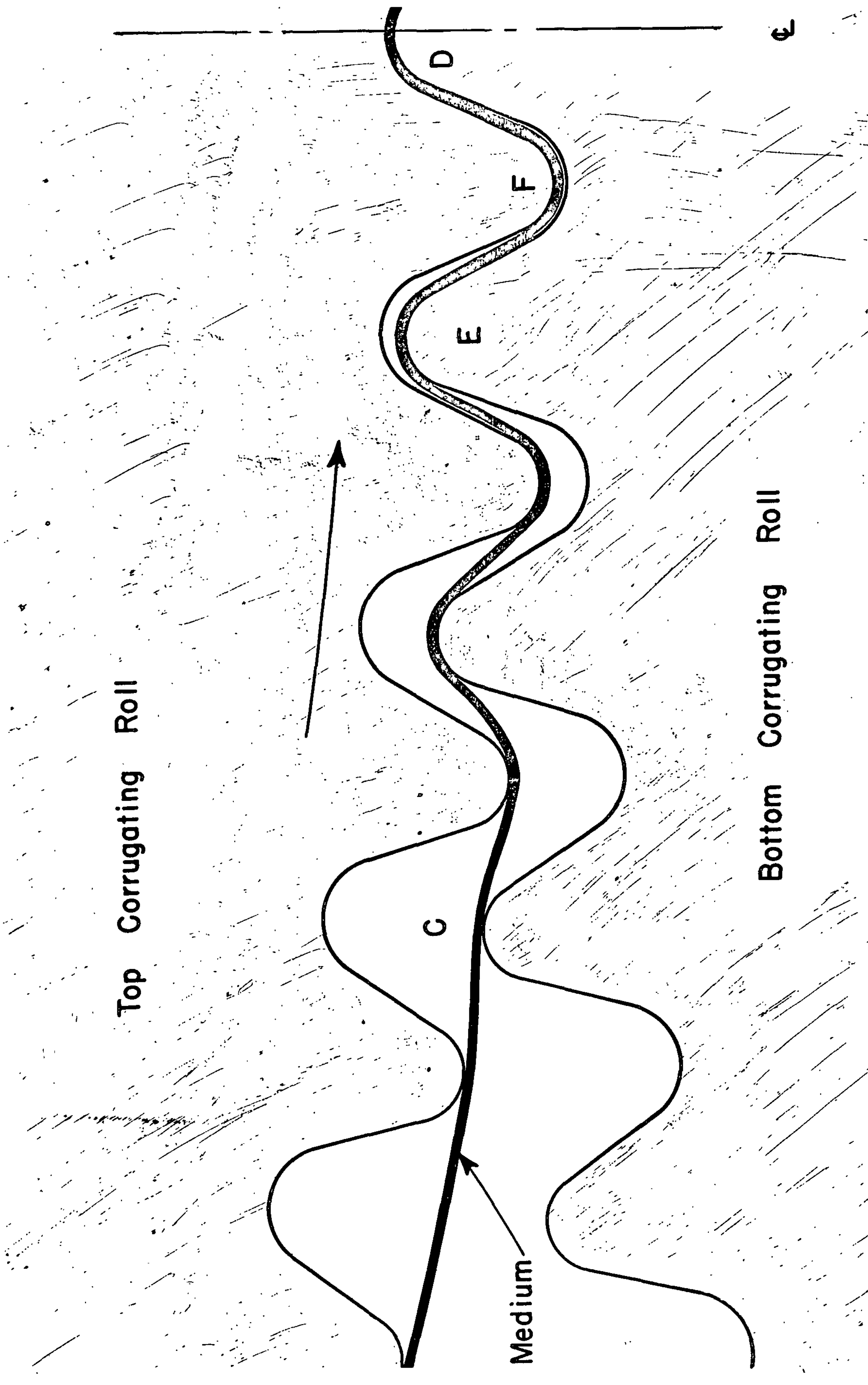


Figure 2. Labyrinth of A-Flute Corrugating Rolls

From the foregoing description of the forces acting on a medium in the single-facing operation up to the center of the corrugating labyrinth, it is apparent that transport tension has an important influence on runnability. Based on the above, the Institute (13) designed a web feeder (shown in Fig. 3) to feed the medium into the labyrinth under minimum tension. The web feeder provides the tension necessary to unwind the medium from the parent roll and transport it over preheater, idler rolls, etc., so that it may be fed to the corrugating labyrinth with minimum tension. The increase in runnability effected by the web feeder is demonstrated very clearly by the results shown in Table VI.

TABLE VI

RUNNABILITY RESULTS

| Sample No. | Runnability, f.p.m.[a] Without Feeder | With Feeder | Difference, % |
|---|---|---|---|
| A | 100 | 450 | 350 |
| D | 125 | 600 | 380 |
| E | 575 | 900+[b] | 56+ |
| F | 900 | 900+[b] | --[c] |

[a]Maximum speed in f.p.m. at which board could corrugate satisfactorily.

[b]Maximum speed at which the medium feed device could be safely operated.

[c]Indeterminate.

Sherman (14) has been granted a patent for a web feeder which guides the medium through a preconditioner and then to the single-facer with both preconditioner and single-facer being equipped with mechanisms for positively gripping and forwarding the web, thereby reducing the transport tension conventionally associated with feeding the medium to the corrugating labyrinth. Early (15) has also been granted a patent

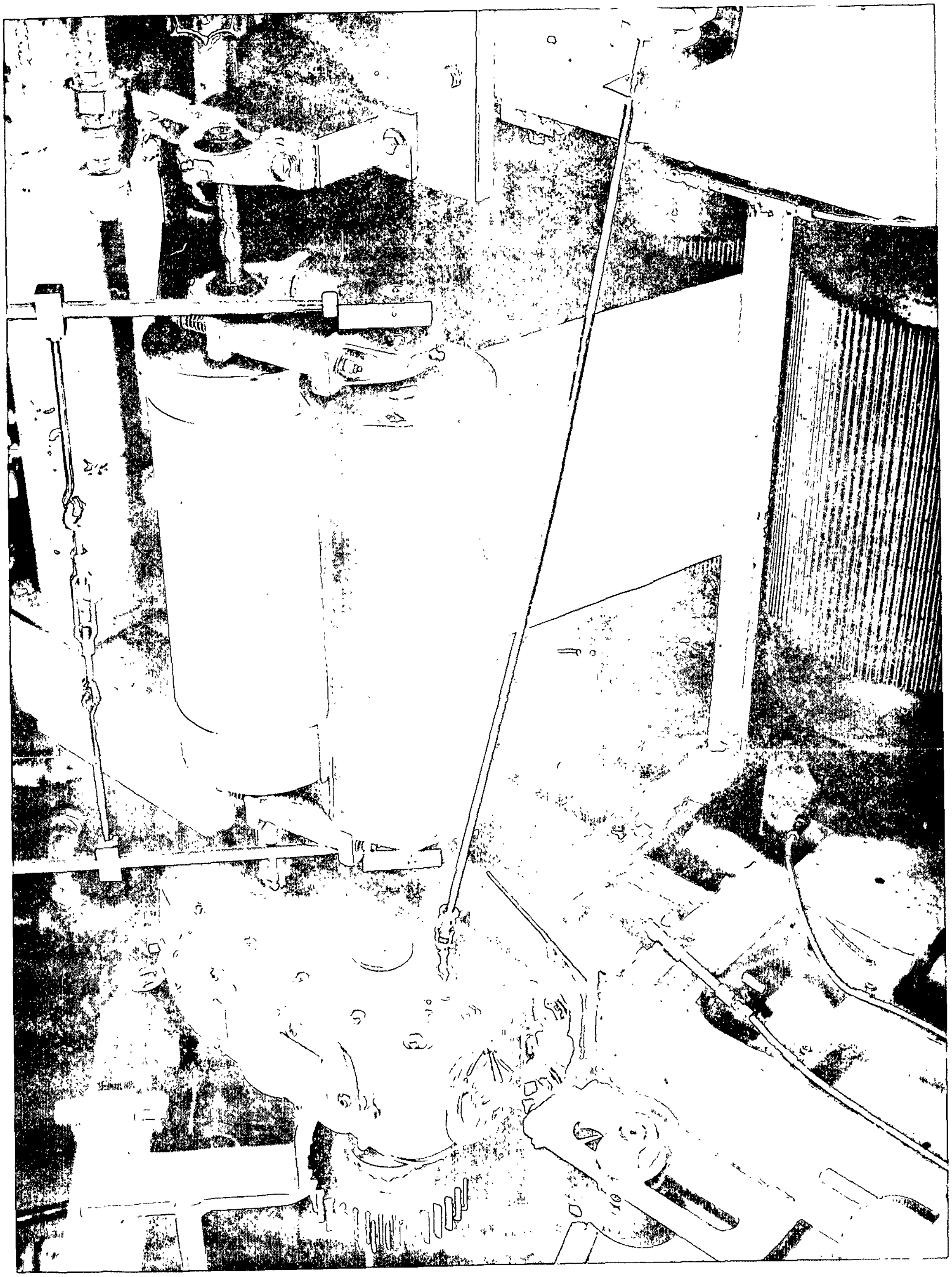

Figure 3. Medium Web Feeder

for a mechanism to control the feeding of both liner and medium to the single-facer, thereby providing a means for maintaining a desired draw factor. In order to control the draw factor, the mechanism developed by Early incorporates a means for reducing the transport tension to which the medium is subjected prior to entering the corrugating labyrinth.

Other devices for controlling tension in the medium on the single-facer have been developed by Schneider (16) and Granozio (17). Schneider's device (or preconditioner as it is described in the literature) consists of a preheater, steam shower, tension loop, and a dunce roll. It is powered by its own drive, and automatically controls tension at a desired level regardless of the feed rate of the medium to the single-facer. Granozio's device utilizes a corrugating mechanism by means of which fluting is performed by passing a suitable web between a pair of endless ribbed belts which are so positioned with respect to each other that a minimum stress is placed on the web during the fluting process.

## Temperature of Corrugating Rolls

In 1965 a limited study of the effect of corrugating roll temperature and moisture content of corrugating medium was carried out at the Institute for the Fourdrinier Kraft Board Institute, Inc. (18). Seven mediums were evaluated - five semichemical, one bogus, and one kraft. With one exception, these mediums fractured when corrugated cold at 150 ft./min. (the exception being the bogus medium). When the temperature of the corrugating rolls was increased to 350°F., all seven mediums could be run at 150 ft./min. or better. On the basis of these results, it appears that higher corrugating roll temperatures promote better runnability.

Peters (19) utilized an experimental unit to study the influence of temperature and other variables on the quality of flute formation. Peters found that the temperature of the corrugating medium during single-facing exerted a decisive influence upon its runnability. Other authors, Harrison (20) and Schultek (21) have studied the role of steam systems in the corrugating operation and concluded that the systems must be designed to provide adequate heat transfer from lowest to highest machine speed in order to produce a quality product, i.e., corrugated single-faced board with well-formed flutes that are well bonded and characterized by uniform flute height.

## Use of Steam Showers

Magnuson (22) has stated that, with the increased steam pressures now in use, frequently the steam being used on the showers is too dry. Because this dry steam is often applied to a relatively dry medium, there may not be enough moisture to condition the medium or even to overcome the hydrophobic nature of the dry surface of the medium. Under this operating condition, plus the higher corrugating speeds being used today, the author noted that problems will occur and manifest themselves in the form of poor runnability or high-low corrugations.

A study at the Institute previously referred to (18) also investigated the effect of steam showers on runnability. One of the conclusions reached was that steam showers were not a substitute for corrugating rolls heated to an adequate temperature.

## Parallelism of Rolls

Koenig (23) cites what he considers to be the principal single-facing defects, their causes, and their effects on the strength properties of corrugated containers. Some of the single-facing defects outlined by Koenig have been discussed previously but may bear repeating here; e.g., he lists the following single-facing defects as influencing runnability:

a) draw tension too high

b) medium too wet or dry

c) not adequate clearance between meshed flutes

d) dirty or excessively worn corrugating rolls

e) medium roll out of round

f) corrugating rolls not parallel

He indicated that cut corrugations are a manifestation of nonparallel corrugating rolls — excessive pressure being applied in one area and too little pressure in another. The subject of roll alignment was also discussed at the 1954 TAPPI Corrugating Conference (24). It was noted that excessive pressure (which may result from nonparallel corrugating rolls) reduces the bursting strength of corrugated board by weakening, or even fracturing, the corrugating medium in the affected area.

## Roll Pressures

Koenig (23) indicates that corrugating rolls with inadequate clearance, i.e., rolls exerting excessively high side-wall pressure, may contribute to poor runnability. Max (25), working with a laboratory corrugator with 8-inch diameter A-flute rolls at a speed of 100 to 130 ft./min., reported that over a nip pressure range of approximately 10 to 160 lb./in. the maximum flat crush occurred at relatively low nip pressures. McKee (6) studied the effect of increases in nip pressure (220 to 865 lb./in.) on the runnability of straw, semichemical, and bogus mediums. He noted that "with the exception of the straw medium, increasing the nip pressure resulted in a lowering of the critical speed level."

## Flute Contour

Wilson (26) has outlined his prerequisites for a good flute contour. He states that in the design and performance of flute contours, certain prerequisites are desired: maximum rigidity of the fluted medium, compensation for high-low corrugations, easy entry of medium, elimination of fractures, maximum flute height, symmetry, and most economical use of medium and adhesive. Wilson states that a truss design of flute construction – i.e., flutes with straight side flanks and tip radii as small as possible – results in a type of beam construction that is simple, strong, and able to provide maximum flat crush for least material.

Wilson also indicates that the flutes of corrugating rolls should be designed for equal clearance all around to accommodate mediums having different calipers because any variation in caliper will prevent the rolls from seating properly. Because two teeth are required to form each flute – and 2-1/2 to 3 flutes are in the process of being formed ahead of the nip position, there is a tension defined as "draw tension," which is associated with the forming process. This draw tension, he continues, is increased greatly by impaired clearances – e.g., at the point where the rolls bottom, the draw tension can far exceed any tension that can be applied to the corrugating web externally. It was also noted that accentuated impairment of clearances will increase draw tension and cause excessive roll deflection – the latter preventing rolls from bottoming properly in the center.

The manufacture and advantages of V-flutes are discussed by Shields (27) – rectilinear edges linked by short-radius curves vs. the long-radius undulations of conventional flutes. In the flat crush test, the rounded parts of V-flutes disappear, Shields states, leaving only the straight edges to support the load like pillars while deviating from their original position an amount dependent on the loss in corrugating board caliper. Because the sides of the flutes assume a vertical position less rapidly than conventional flutes, the author concluded that greater resistance to crushing results.

Wilson (28) has also described the W-S flute design which eliminates any speed differential between the flute tips of the top corrugating roll and the valley of the bottom roll as they come in contact. This is accomplished by recessing the valley of the top roll so that it cannot possibly come in contact with the medium. Wilson advises that this design eliminates slide action and wear from the latter cause and provides a better bond, better quality, higher speeds, and trouble-free operation — the latter advantages being based on experience with the new rolls.

In his studies, Nitchie (29) examines the modified involute and bridge truss theories of design for corrugated roll teeth. He states that because of improvements in medium quality — greater resistance to cutting and fracture — and the availability of better adhesives and steam systems, the sharper-pointed, straight-sided flute has become practical. Conclusions drawn by Nitchie from data obtained on B- and C-flute single-facers of four leading manufacturers indicate that straight-sided flute contours produce economies amounting to 9% in terms of reduced medium and adhesive consumption.

In 1953, Werner (30) published a fundamental discussion of flute contours and concluded that the advantages of flute contours with considerable clearance on the sides were reduced high-low corrugations (more uniform board caliper) and higher flat crush.

## EFFECT OF MATERIAL VARIABLES

Based on a number of studies at the Institute, McKee and Gander (31) have noted that the medium will fracture if the induced strains exceed the allowable strains for the particular medium under the prevailing conditions of heat, moisture, and rate of straining. The major strains are considered to be transport, bending, shear, and transverse compression. They note that the transport strains are dependent on the brake tension and frictional resistance of the medium as it is drawn into the corrugating labyrinth. The bending and shear strains are induced in the medium as the medium is formed to the flute contour. At the center of the labyrinth, high transverse compression stresses are imposed on the medium which results in approximately a 35% reduction in caliper. Based on the above, the authors indicate that the properties of the medium which appear to be of importance to runnability are (1) coefficient of friction, (2) critical bending strain, (3) critical shear strain, (4) transverse compression characteristics, and (5) caliper.

Townsend and Lemon (32) have written that the responsibility of the paper mill is to provide a product with uniform controlled moisture (approximately 6%), uniform caliper, uniform weight and finish, uniform porosity to promote uniform receptivity to adhesives, uniform color, whereas the responsibility of the converter is to provide adequate warehousing - ideally under controlled temperature and humidity. Adequate warehousing, according to these authors, should also include (a) vertical stacking to prevent flattening of rolls, (b) perimeter type storage to prevent accumulation of old stock, and (c) careful attention to operational and quality control procedures throughout the conversion process.

# DISCUSSION OF RUNNABILITY RESULTS

## EFFECT OF WEB TENSION

As mentioned previously, seven corrugating medium samples were evaluated for runnability at three web tensions, namely, 0.25, 1.0, and 2.0 lb./in. of medium width. The results are summarized in Table VII and illustrated in Fig. 4. Also shown in the table and figure are (1) draw factor measurements taken at the maximum corrugating speed, (2) the temperature of the corrugating medium entering the corrugating nip at two speeds — 150 and 450 f.p.m., and (3) the average flute tip caliper measured on the single-face sample obtained at the maximum runnability speed.

It should be mentioned that the above tension values correspond to the transport tension on the web and do not reflect the additional tension caused by friction imposed on the medium during its passage around the top corrugating roll and through the corrugating labyrinth. In addition, it should be noted that the tension values are "average" values in the sense that they do not reflect the dynamic high frequency variations in tension which occur during corrugating.

As would be expected, the runnability decreased with increasing web tension, though the effect is obscured for certain mediums because they corrugated satisfactorily at the maximum speed of 1000 f.p.m. at two or more of the tension levels. In these instances the value of 1000 f.p.m. may be regarded as a lower limit because higher speeds would have been required to fracture the flutes. For the three mediums which exhibited runnability values less than 1000 f.p.m. at all three tension levels, the composite averages indicate a decrease in runnability of from about 100 to 150 f.p.m. per unit change in web tension.

TABLE VII

EFFECT OF WEB TENSION ON RUNNABILITY

| No. | Type of Medium | Roll No. | Runnability, f.p.m. | | | Draw Factor[a] | | | Flute Tip Caliper, pt.[a] | | | Medium Temperature,[b] °F. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 150 f.p.m. | | | 450 f.p.m. | | |
| | | | Web Tension, lb./in. | | | Web Tension, lb./in. | | | Web Tension, lb./in. | | | Web Tension, lb./in. | | | Web Tension, lb./in. | | |
| | | | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 |
| 1 | 26-Lb. semichem. | 28 | 1000[c] | 900 | 200 | 1.556 | 1.548 | 1.549 | 6.58 | 6.55 | 6.32 | 166 | 173 | 173 | 160 | 166 | 169 |
| 2 | 26-Lb. semichem. | 59 | 950 | 900 | 725 | 1.552 | 1.552 | 1.558 | 5.72 | 5.80 | 5.88 | 150 | 151 | 153 | 145 | 150 | 150 |
| 3 | 26-Lb. kraft | 46 | 450 | 275 | 200 | 1.555 | 1.553 | 1.550 | 6.21 | 6.52 | 6.46 | 175 | 181 | 194 | 172 | 179 | 195 |
| 4 | 26-Lb. kraft | 144 | 1000[c] | 1000[c] | 925 | 1.564 | 1.554 | 1.557 | 6.74 | 6.98 | 6.94 | 166 | 169 | 170 | -- | 169 | 175 |
| 5 | 26-Lb. bogus | 84 | 1000[c] | 1000[c] | 1000[c] | 1.561 | 1.555 | 1.547 | 6.16 | 6.29 | 6.48 | 164 | 173 | 174 | 169 | 173 | 174 |
| 6 | 26-Lb. bogus | 88 | 1000[c] | 1000[c] | 775 | 1.545 | 1.535 | 1.536 | 6.11 | 6.39 | 5.84 | 170 | 166 | 178 | 165 | 171 | 176 |
| 7 | 33-Lb. semichem. | 148 | 600 | 475 | 425 | 1.540 | 1.540 | 1.525 | 8.04 | 7.44 | 7.72 | 163 | 161 | 173 | 155 | 156 | 165 |
| Composite average: | | | 667[d] | 550[d] | 450[d] | 1.553 | 1.548 | 1.546 | 6.51 | 6.57 | 6.52 | 165 | 168 | 174 | 161 | 166 | 172 |

[a]Measured at runnability speed.

[b]Temperature of medium entering corrugating nip.

[c]Corrugated satisfactorily at maximum speed employed.

[d]Average for medium samples 2, 3 and 7 only.

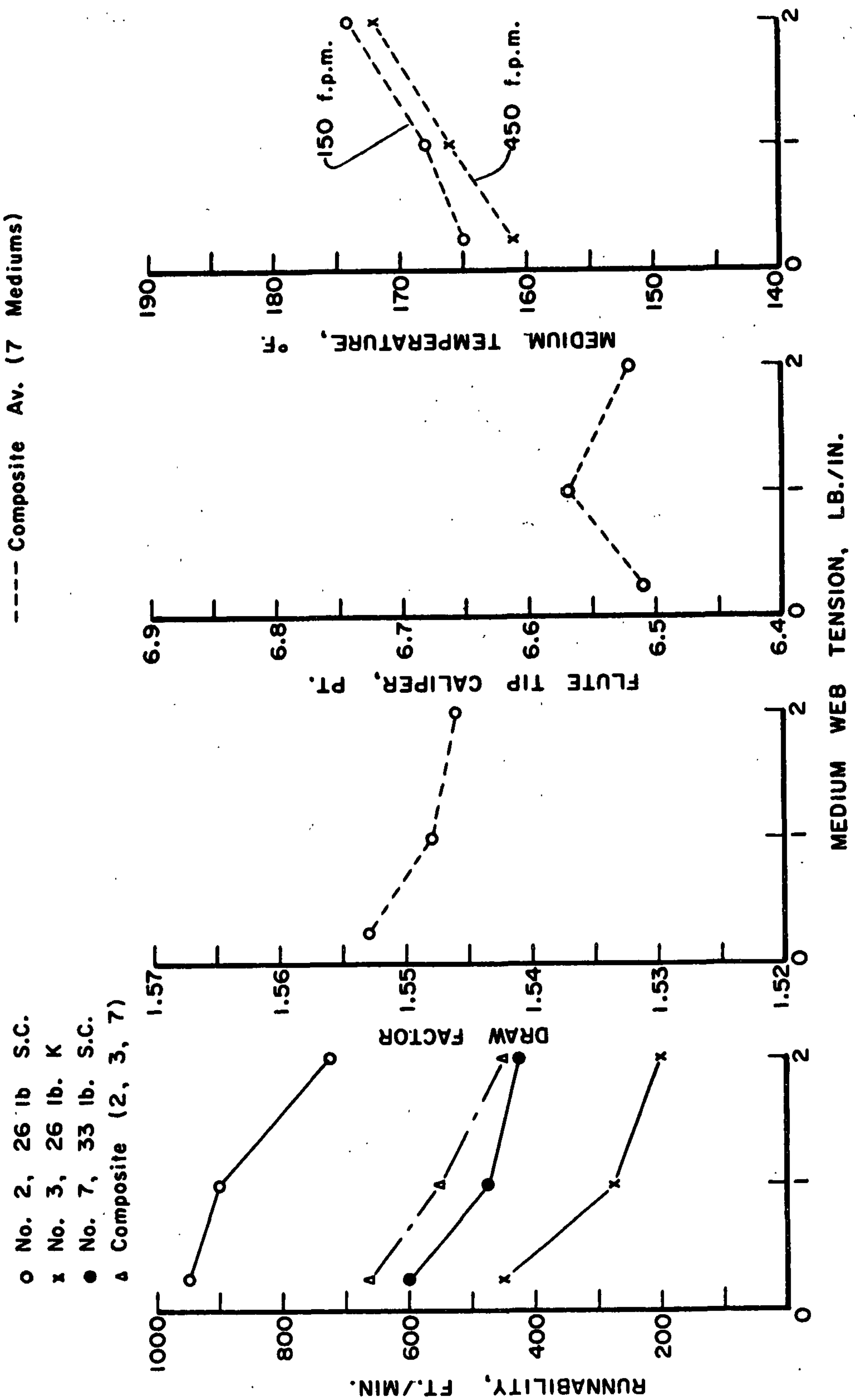


Figure 4. Effect of Web Tension on Runnability and Related Factors

It may be noted that medium sample No. 1 exhibited a decrease in runnability from 900 to 200 f.p.m. when the tension was changed from 1 to 2 lb./in. This decrease was considerably greater than was obtained with any of the other medium samples, and may have been caused by a change in quality of the medium in the roll inasmuch as in other phases of the study runnabilities as high as 900 to 1000 f.p.m. at 1 lb./in. tension could not be obtained with this medium sample.

The runnability results for medium samples No. 2, 3, and 7 were analyzed statistically as shown in Table VIII. [Note: The other medium samples (No. 1, 4, 5, and 6) were excluded from the analysis to avoid the bias that would result from including the 1000 f.p.m. runnabilities.] While the data are limited, the analysis indicated that the effects of tension were statistically significant at the 0.01 level. In addition, the differences in runnability between medium samples were also statistically significant.

With regard to the other characteristics, it may be noted that there was a slight decrease in draw factor with increasing tension. The change amounted to about 0.4%, on the average, in going from 0.25 to 2.0 lb./in. tension. While the change in draw was small, the analysis indicated it was statistically significant at the 0.05 level.

Flute tip caliper did not exhibit a consistent trend to increase or decrease with increasing web tension, and the analysis in Table VIII indicates that the differences were not statistically significant. There was, however, a significant interaction between tension and medium. As may be noted in Table VII, the various mediums exhibited opposing trends and this probably accounts for the significant interaction. There is some evidence, therefore, that tension may significantly affect flute tip caliper; however, the direction of the effect varies from medium-to-medium.

TABLE VIII

STATISTICAL ANALYSIS OF THE EFFECTS OF WEB TENSION ON RUNNABILITY AND RELATED FACTORS

| Source of Variance | Degrees of Freedom | Mean Square | F |
|---|---|---|---|
| | Runnability[e] | | |
| Between tensions | 2 | 35,278 | 21.62[a] |
| Between mediums | 2 | 233,819 | 143.28[a] |
| Residual error | 4 | 1,632 | |
| | Draw Factor | | |
| Between tensions | 2 | 0.000097 | 4.71[b] |
| Between mediums | 6 | 0.000230 | 11.17[a] |
| Residual error | 12 | 0.000021 | |
| | Flute Tip Caliper | | |
| Between tensions[c] | 2 | 0.0674 | 0.16 |
| Between mediums[c] | 6 | 11.7503 | 27.63[a] |
| Interaction | 12 | 0.4252 | 4.84[a] |
| Residual error | 189 | 0.0879 | |
| | Temperature (150 f.p.m.) | | |
| Between tensions | 2 | 138.15 | 9.40[a] |
| Between mediums | 6 | 269.27 | 18.32[a] |
| Residual error | 12 | 14.70 | |
| | Temperature (450 f.p.m.)[d] | | |
| Between tensions | 2 | 165.72 | 11.79[a] |
| Between mediums | 5 | 408.36 | 29.05[a] |
| Residual error | 10 | 14.06 | |

[a]Significant at the 0.01 level.

[b]Significant at the 0.05 level.

[c]Tension was considered to be a fixed factor; medium samples a random factor.

[d]Sample 4 was excluded because of a missing value at 0.25 lb./in.

[e]Analysis restricted to Samples 2, 3, and 7.

It is believed that this conclusion should be interpreted with caution, however, because there was no replication of runs to provide an estimate of between-run variability. If the latter were large relative to the variability within runs, the apparent interaction between tension and type of medium would possibly become nonsignificant.

In the case of temperature, the results indicate that the temperature of the medium entering the nip increased slightly (5 to 6%) as web tension increased from 0.25 to 2.0 lb./in. Apparently, higher heat transfer occurred as the medium passed over the medium preheater due to better contact at higher web tensions. The analysis in Table VIII indicates that the increases in temperature were statistically significant.

It may be remarked that the runnability, draw, and temperature evaluations involved no replication. The lack of replication results in a loss in sensitivity in the statistical evaluations and prevents analyzing possible interactions between type of medium and web tension. For example, it is possible that certain mediums are more sensitive to increased tension than others; however, without replicate runs it would be difficult to determine if the differences in sensitivity to tension were significant. In the case of flute tip caliper, ten replicate measurements were made. This permitted an improved estimate of residual error and made it possible to evaluate the significance of the interaction term — indicating in this case that the various mediums apparently responded differently to changes in web tension in so far as flute tip caliper was concerned. While this replication is helpful, it does not provide an estimate of the variability between runs. If the differences between replicate runs were large relative to the within run variability, the interaction might fail to attain statistical significance. Thus, even in this case, replication of runs would be desirable to assist in interpreting the differences in behavior exhibited by the various mediums.

EFFECT OF STEAM SHOWERS

As mentioned previously, corrugating runs were carried out using three steam pressures on the showers, namely, 0 (no steam shower), 14, and 28 p.s.i. The 14 p.s.i. pressure corresponds to the normal operating pressure for the Institute's corrugator. The runnability results are summarized in Table IX and Fig. 5.

In Table IX, it may be noted that both 26-lb. semichemical mediums exhibited appreciable increases in runnability when shower pressure was changed from 0 to 14 p.s.i.; however, no increase in the runnability speed was observed when the shower pressure was increased from 14 to 28 p.s.i. The 33-lb. semichemical sample behaved similarly, though a slight increase in runnability was obtained at the highest steam pressure.

Of the two 26-lb. kraft mediums, one exhibited an increasing runnability with increased shower pressure with the greatest increase occurring in going from 0 to 14 p.s.i. shower pressure. The other kraft medium gave a runnability of 900 f.p.m. with no steam shower and runnabilities of 1000 f.p.m. at both higher shower pressures. In this case it appears that the use of the shower was beneficial to runnability; however, the sensitivity to higher steam pressures cannot be estimated because of the high runnability quality of Medium 4.

Both bogus mediums corrugated satisfactorily in so far as runnability is concerned at 1000 f.p.m. at both 0 and 14 p.s.i. shower pressures. At the highest shower pressure one medium corrugated satisfactorily at 1000 f.p.m. while the other exhibited a slight decrease in runnability to 900 f.p.m. Because of the high runnability quality of these mediums, it is impossible to draw any positive conclusion regarding their runnability sensitivity to steam showers.

TABLE IX

EFFECT OF STEAM SHOWERS ON RUNNABILITY

| No. | Type of Medium | Roll No. | Runnability, f.p.m.[a] Shower Pressure, p.s.i. 0 | 14 | 28 | Draw Factor[b] Shower Pressure, p.s.i. 0 | 14 | 28 | Flute Tip Caliper, pt.[b] Shower Pressure, p.s.i. 0 | 14 | 28 | Medium Temperature, °F. 150 f.p.m. Shower Pressure, p.s.i. 0 | 14 | 28 | Medium Temperature, °F. 450 f.p.m. Shower Pressure, p.s.i. 0 | 14 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 26-Lb. semichem. | 28 | 450 | 600 | 600 | 1.557 | 1.548 | 1.545 | 6.49 | 6.00 | 6.12 | 150 | 168 | 171 | 144 | 168 | 168 |
| 2 | 26-Lb. semichem. | 59 | 600 | 900 | 900 | 1.553 | 1.552 | 1.549 | 5.77 | 5.80 | 5.50 | 128 | 151 | 148 | 125 | 150 | 149 |
| 3 | 26-Lb. kraft | 46 | 225 | 325 | 375 | 1.557 | 1.557 | 1.555 | 6.94 | 6.76 | 6.14 | 177 | 181 | 199 | 168 | 179 | 195 |
| 4 | 26-Lb. kraft | 144 | 900 | 1000[c] | 1000[c] | 1.560 | 1.554 | 1.576 | 7.07 | 6.98 | 6.55 | 151 | 169 | 173 | -- | 169 | 177 |
| 5 | 26-Lb. bogus | 84 | 1000[c] | 1000[c] | 1000[c] | 1.564 | 1.555 | 1.556 | 6.60 | 6.29 | 6.32 | 153 | 173 | 180 | 150 | 173 | 177 |
| 6 | 26-Lb. bogus | 88 | 1000[c] | 1000[c] | 900 | 1.546 | 1.535 | 1.535 | 6.44 | 6.39 | 5.82 | 140 | 166 | 160 | 139 | 171 | 163 |
| 7 | 33-Lb. bemichem. | 148 | --[d] | 475 | 500 | --[d] | 1.540 | 1.539 | --[d] | 7.44 | 7.82 | 146[d] | 161 | 178 | --[d] | 156 | 168 |
| Composite average:[e] | | | 425 | 608 | 625 | 1.556 | 1.550 | 1.553 | 6.55 | 6.37 | 6.08 | 150 | 168 | 172 | 145 | 168 | 172 |

[a]Evaluated at 1 lb./in. web tension.

[b]Measured at runnability speed.

[c]Corrugated satisfactorily at maximum speed employed in this study.

[d]Medium was severely fractured at minimum speed (150 f.p.m.) employed in this study.

[e]For runnability: Samples 4, 5, 6,and 7 were omitted from average; for draw factor, tip caliper and temperature, Sample 7 was omitted from average.

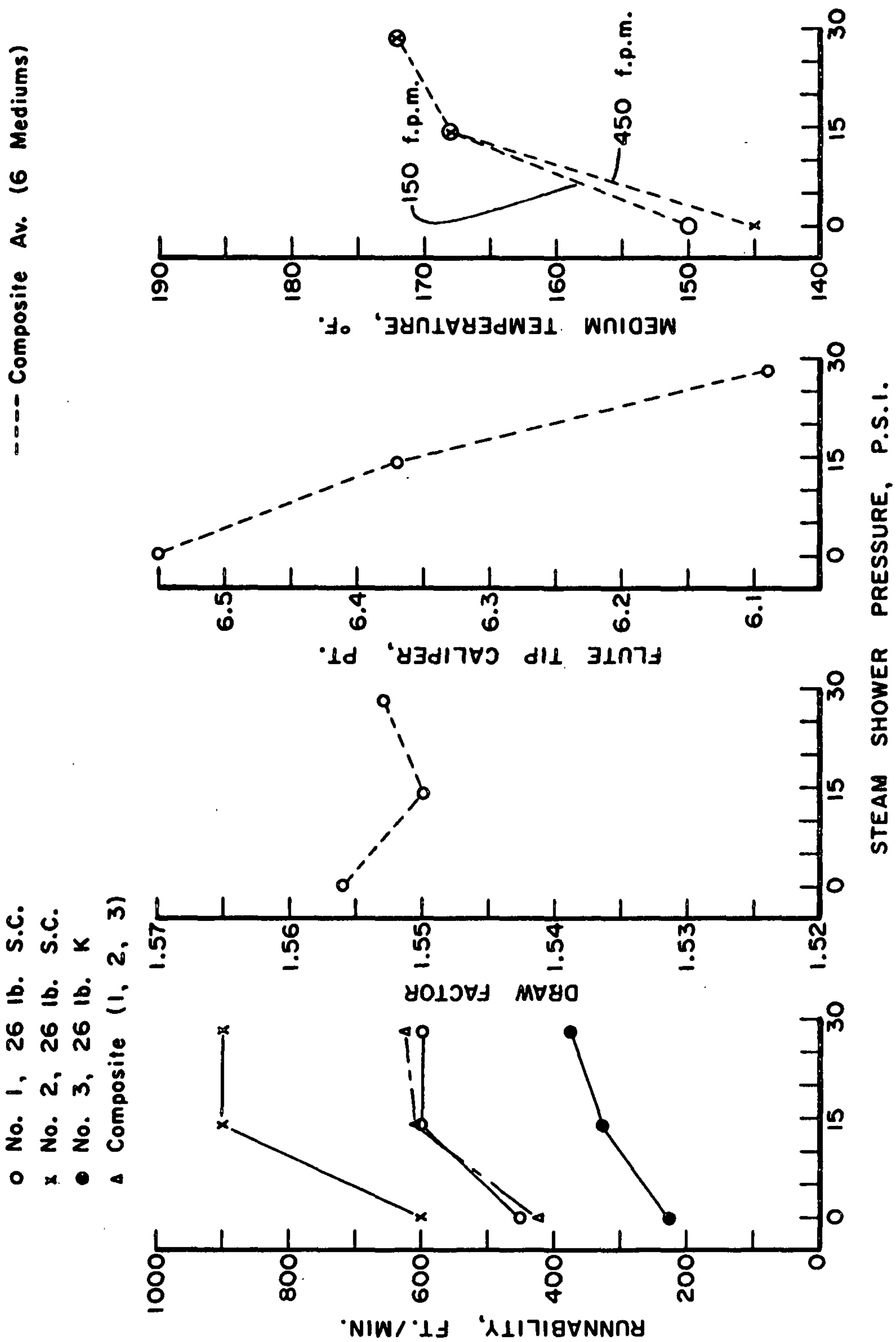


Figure 5. Effect of Steam Showers on Runnability and Related Factors

For the mediums exhibiting runnabilities below 1000 f.p.m. at all levels of shower pressure (Samples No. 1, 2, 3, and 7), it appears that the use of steam showers increases runnability. However, beyond a certain point, further increases in shower pressure result in small or even no increases in runnability speed.

A statistical analysis of the results is shown in Table X. In the case of runnability, the analysis was restricted to Mediums No. 1, 2, and 3 which exhibited runnabilities less than 1000 f.p.m. but more than 150 f.p.m. at all shower pressures. As may be noted, the effect of shower pressure on runnability was significant at the 0.01 level indicating that shower pressure significantly increases runnability.

The draw factors at maximum runnability speed exhibited little change with increasing shower pressure and the analysis indicated that the changes were not significant. As would be expected, the use of steam significantly increased the temperature of the medium entering the corrugating nip. However, the greatest temperature change was obtained in going from 0 to 14 p.s.i. shower pressure.

It may be noted that flute tip calipers decreased on the average as shower pressure increased, and the changes were significant at the 0.01 level. This indicates that the use of steam tended to plasticize the medium resulting in greater permanent reductions in tip caliper.

## EFFECT OF AMOUNT OF MEDIUM PREHEAT

As mentioned previously, the effects of the amount of preheat on runnability were studied employing three preheat conditions. They were (1) no medium preheat, (2) half wrap on preheater (about 90° contact), and (3) full wrap on preheater (about 180° contact). The normal operating condition utilizes full wrap on the preheater. It should be kept in mind that the runs were carried out using the "normal" steam

TABLE X

STATISTICAL ANALYSIS OF THE EFFECTS OF SHOWER PRESSURE ON RUNNABILITY AND RELATED FACTORS

| Source of Variance | Degrees of Freedom | Mean Square | $F$ |
|---|---|---|---|
| **Runnability[c]** | | | |
| Between shower pressures | 2 | 36,944 | 11.56[a] |
| Between mediums | 2 | 181,319 | 56.76[a] |
| Residual error | 4 | 3,194 | |
| **Draw Factor[d]** | | | |
| Between shower pressures | 2 | 0.0000545 | 1.47 |
| Between mediums | 5 | 0.0002178 | 5.87[a] |
| Residual error | 10 | 0.0000371 | |
| **Flute Tip Caliper[d]** | | | |
| Between shower pressures[b] | 2 | 3.407 | 11.55[a] |
| Between mediums[b] | 5 | 4.809 | 64.12[a] |
| Interaction | 10 | 0.295 | 3.93[a] |
| Residual error | 162 | 0.075 | |
| **Temperature (150 f.p.m.)[d]** | | | |
| Between shower pressures | 2 | 828.7 | 36.7[a] |
| Between mediums | 5 | 620.0 | 27.4[a] |
| Residual error | 10 | 22.6 | |

[a] Significant at the 0.01 level.

[b] Shower pressure was considered to be a fixed factor; therefore, its mean square is compared to the interaction mean square. Medium sample was considered a random factor; therefore, its mean square is compared against the residual error.

[c] Analysis restricted to Samples 1, 2, and 3.

[d] Sample 7 was excluded because values could not be obtained at 0 shower pressure due to severe fracturing.

shower pressure (14 p.s.i.); therefore, even when the medium preheater was not used, the steam showers supplied a substantial amount of heat to the medium.

The runnability results are summarized in Table XI and illustrated in Fig. 6. When the amount of preheat was increased from no preheat to a half wrap on the preheater, runnability increased for each medium. The increases in speed ranged from 100 to 175 f.p.m. in those comparisons where the maximum speed of 1000 f.p.m. was not reached. When the amount of preheat was increased from half to full wrap on the preheater, the runnability decreased for one of the kraft mediums, remained constant for one of the 26-lb. semichemical mediums, and increased for three of the mediums (one bogus, one 26-lb. semichemical, and the 33-lb. semichemical medium). Taken as a whole, the data suggest that the greatest increases in runnability were obtained in going from no preheat to a half wrap on the preheater and a lesser (or at least less consistent) trend to increased runnability was obtained in going from half to full wrap on the preheater. The medium temperatures entering the nip show a similar trend on the average. Thus, the average change in medium temperature in going from no wrap to full wrap was 8 to 10°F., whereas the average increase in temperature in going from half to full wrap was only 4°F.

One of the bogus mediums (No. 6) appeared to be quite sensitive to the amount of preheat inasmuch as its runnability decreased from +1000 f.p.m. at full preheater wrap to 525 f.p.m. with no preheater. This medium generally exhibited satisfactory runnabilities of +1000 f.p.m. in previous phases of the study involving web tension and steam shower changes. This suggests that preheat was more important than use of showers for this medium; however, this conclusion should be treated with caution inasmuch as changes in medium quality between rolls may also be involved.

TABLE XI

EFFECT OF AMOUNT OF MEDIUM PREHEAT ON RUNNABILITY

| | | | Runnability, f.p.m.[a] | | | Draw Factor[b] | | | Flute Tip Caliper, pt.[b] | | | Medium Temperature, °F. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 150 f.p.m. | | | 450 f.p.m. | | |
| No. | Type of Medium | Roll No. | No Pre-heat | Half Wrap on Pre-heater | Full Wrap on Pre-heater | No Pre-heat | Half Wrap on Pre-heater | Full Wrap on Pre-heater | No Pre-heat | Half Wrap on Pre-heater | Full Wrap on Pre-heater | No Pre-heat | Half Wrap on Pre-heater | Full Wrap on Pre-heater | No Pre-heat | Half Wrap on Pre-heater | Full Wrap on Pre-heater |
| 1 | 26-Lb. semichem. | 29 | 450 | 625 | 625 | 1.547 | 1.548 | 1.548 | 6.18 | 6.68 | 6.09 | 155 | 158 | 165 | 152 | 155 | 161 |
| 2 | 26-Lb. semichem. | 60 | 450 | 625 | 775 | 1.560 | 1.557 | 1.562 | 5.93 | 5.65 | 5.60 | 144 | 150 | 152 | 137 | 145 | 150 |
| 3 | 26-Lb. kraft | 47 | 325[d] | 425[d] | 350[d] | 1.555 | 1.557 | 1.559 | 6.59 | 6.51 | 6.12 | 151 | 159 | 170 | 143 | 158 | 166 |
| 4 | 26-Lb. kraft | 145 | 775 | 1000[c] | 1000[c] | 1.547 | 1.548 | 1.544 | 6.73 | 6.85 | 6.74 | 164 | 163 | 166 | 156 | 166 | 164 |
| 5 | 26-Lb. bogus | 85 | 900 | 1000[c] | 1000[c] | 1.542 | 1.550 | 1.553 | 6.03 | 5.99 | 5.95 | 154 | 170 | 164 | 154 | 167 | 165 |
| 6 | 26-Lb. bogus | 89 | 525 | 750 | 1000[c] | 1.534 | 1.540 | 1.538 | 5.60 | 5.75 | 6.14 | 143 | 162 | 159 | 141 | 160 | -- |
| 7 | 33-Lb. semichem. | 149 | 325 | 450 | 475 | 1.524 | 1.530 | 1.525 | 7.56 | 7.72 | 7.89 | 148 | 152 | 165 | 145 | 150 | 160 |
| Composite average: | | | 388[e] | 531[e] | 556[e] | 1.544 | 1.547 | 1.547 | 6.37 | 6.45 | 6.36 | 151 | 159 | 163 | 147 | 157 | 161 |

[a]Evaluated using 1 lb./in. web tension.

[b]Measured at runnability speed.

[c]Corrugated satisfactorily at maximum speed employed in this study.

[d]Evaluated at minimum (0.25 lb./in.) web tension because medium could not be corrugated satisfactorily at 1 lb./in. tension.

[e]Composite of Samples 1, 2, 3, and 7.

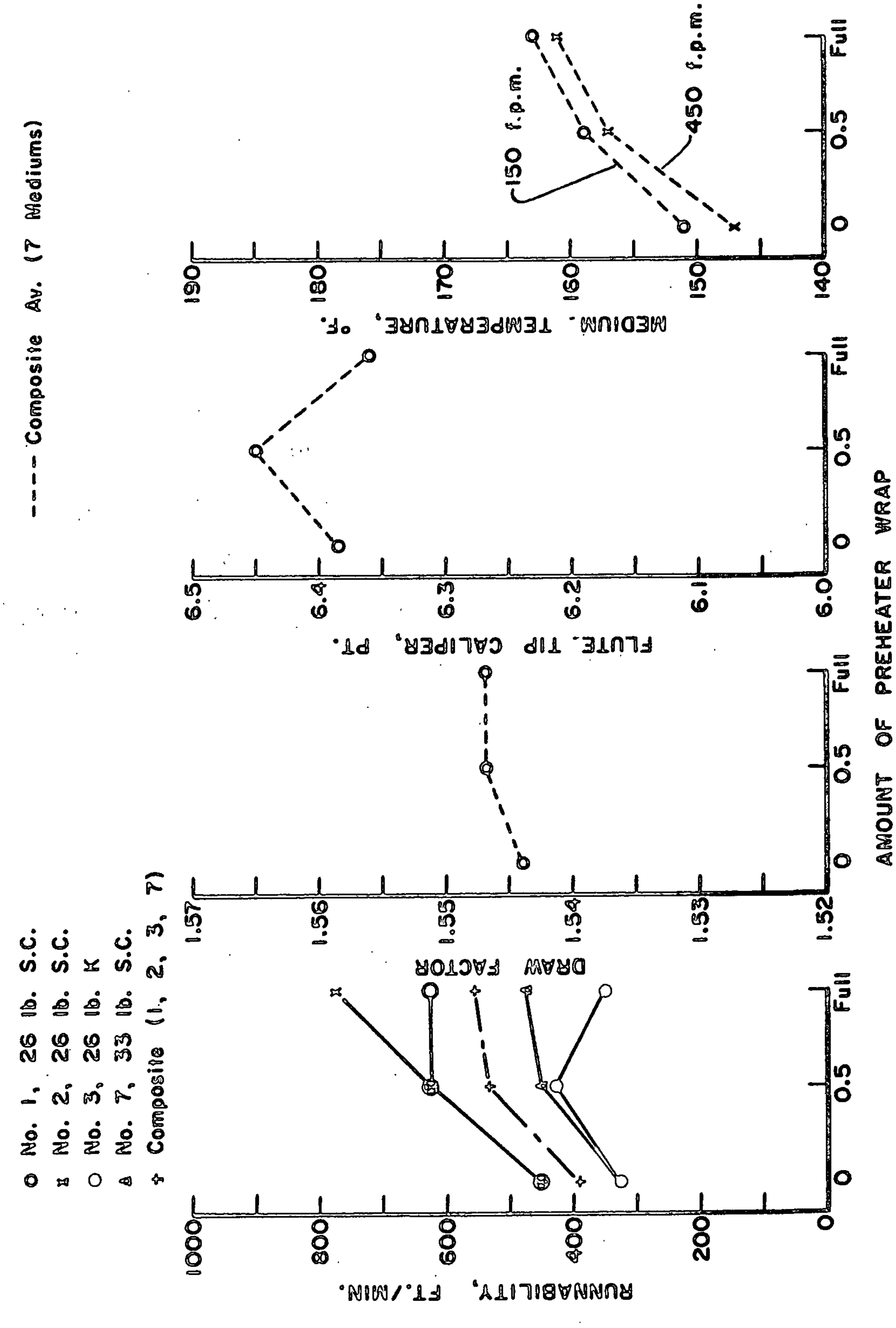


Figure 6. Effect of Amount of Medium Preheat on Runnability and Related Factors

It may be interesting to note that it was necessary to use a web tension of 0.25 lb./in. in corrugating kraft medium No. 3 in this phase to obtain runnabilities in excess of 150 f.p.m. In the previous two phases, runnabilities ranging from 200 to 400 f.p.m. were obtained using a web tension of 1.0 lb./in. The above suggests that the characteristics of the two rolls involved were somewhat different even though they were manufactured at essentially the same time. For this reason, care must be taken in comparing results obtained in the several phases of this study.

The statistical analysis in Table XII indicates that runnability was significantly affected by the amount of medium preheat. Medium temperatures also increased significantly with increasing amounts of preheat as would be expected. It is interesting to note that even with no preheat, the steam showers raised the temperature of the medium to almost the same levels as were attained when both preheaters and showers were used in the web tension phase.

In contrast to the above the draw factors at maximum runnability and the flute tip calipers did not exhibit a significant change with changes in preheat though in the latter case there was a significant interaction between preheat and medium.

## EFFECT OF ROLL PRESSURE

The effects of roll pressure on runnability were studied using three levels of pressure, namely, 187, 327, and 513 lb./in. of medium width. The normal operating pressure for the Institute's corrugator is 327 lb./in.

Referring to Table XIII or Fig. 7, it may be noted that the runnability speeds did not vary in any consistent pattern as roll pressures were increased. The statistical analysis in Table XIV (based on results for Mediums 1, 2, 3, and 7) indicated that roll pressure did not significantly affect runnability. It should be

TABLE XII

STATISTICAL ANALYSIS OF THE EFFECT OF THE AMOUNT OF MEDIUM PREHEAT ON RUNNABILITY

| Source of Variance | Degrees of Freedom | Mean Square | F |
|---|---|---|---|
| | Runnability[c] | | |
| Between amount of preheat | 2 | 33,177 | 7.86[b] |
| Between mediums | 3 | 42,500 | 10.07[a] |
| Residual error | 6 | 4,218 | |
| | Draw Factor | | |
| Between amount of preheat | 2 | 0.0000205 | 2.54 |
| Between mediums | 6 | 0.0003885 | 48.06[a] |
| Residual error | 12 | 0.0000081 | |
| | Flute Tip Caliper | | |
| Between amount of preheat[d] | 2 | 0.160 | 0.33 |
| Between mediums[d] | 6 | 14.219 | 192.15[a] |
| Interaction | 12 | 0.485 | 6.55[a] |
| Residual error | 189 | 0.074 | |
| | Temperature (150 f.p.m.) | | |
| Between amount of preheat | 2 | 249.475 | 10.99[a] |
| Between mediums | 6 | 87.317 | 3.85[b] |
| Residual error | 12 | 22.699 | |
| | Temperature (450 f.p.m.)[e] | | |
| Between amount of preheat | 2 | 271.725 | 21.25[a] |
| Between mediums | 5 | 138.756 | 10.85[a] |
| Residual error | 10 | 12.789 | |

[a] Significant at the 0.01 level.

[b] Significant at the 0.05 level.

[c] Analysis restricted to Samples 1, 2, 3, and 7.

[d] Amount of preheat was considered to be a fixed factor; therefore, its mean square is compared to the interaction mean square. Medium sample was considered a random factor; therefore its mean square is compared against the residual error.

[e] Sample 6 omitted because of missing value.

TABLE XIII

EFFECT OF ROLL PRESSURE ON RUNNABILITY

| No. | Type of Medium | Roll No. | Runnability, f.p.m.[a] | | | Draw Factor[b] | | | Flute Tip Caliper, pt.[b] | | | Medium Temperature, °F. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Roll Pressure, lb./in. | | | Roll Pressure, lb./in. | | | Roll Pressure, lb./in. | | | 150 f.p.m. Roll Pressure, lb./in. | | | 450 f.p.m. Roll Pressure, lb./in. | | |
| | | | 187 | 327 | 513 | 187 | 327 | 513 | 187 | 327 | 513 | 187 | 327 | 513 | 187 | 327 | 513 |
| 1 | 26-Lb. semichem. | 29 | 750 | 625 | 725 | 1.544 | 1.548 | 1.550 | 6.78 | 6.09 | 5.59 | 162 | 165 | 166 | -- | 161 | 161 |
| 2 | 26-Lb. semichem. | 60 | 750 | 775 | 650 | 1.557 | 1.562 | 1.561 | 6.14 | 5.60 | 5.64 | 154 | 152 | 150 | 151 | 150 | 150 |
| 3 | 26-Lb. kraft | 47 | 375[d] | 350[d] | 700[d] | 1.553 | 1.559 | 1.552 | 6.33 | 6.12 | 6.07 | 168 | 170 | 166 | -- | 166 | 166 |
| 4 | 26-Lb. kraft | 145 | 725 | 1000[c] | 900 | 1.550 | 1.544 | 1.560 | 7.46 | 6.74 | 6.35 | 185 | 166 | 175 | 180 | 164 | 178 |
| 5 | 26-Lb. bogus | 85 | 1000[c] | 1000[c] | 1000[c] | 1.553 | 1.553 | 1.555 | 6.69 | 5.95 | 5.65 | 168 | 164 | 172 | 173 | 165 | 172 |
| 6 | 26-Lb. bogus | 89 | 1000[c] | 1000[c] | 1000[c] | 1.536 | 1.538 | 1.536 | 6.74 | 6.14 | 5.14 | 167 | 159 | 164 | 164 | -- | 165 |
| 7 | 33-Lb. semichem. | 149 | 450 | 475 | 500 | 1.524 | 1.525 | 1.527 | 8.89 | 7.89 | 7.19 | 175 | 165 | 167 | 167 | 160 | 163 |
| Composite average: | | | 581[e] | 556[e] | 644[e] | 1.545 | 1.547 | 1.549 | 7.00 | 6.36 | 5.95 | 168 | 163 | 166 | 167 | 161 | 165 |

[a]Evaluated using 1 lb./in. medium web tension.
[b]Measured at runnability speed.
[c]Corrugated satisfactorily at maximum speed employed in this study.
[d]Evaluated using minimum web tension (0.25 lb./in.) because medium would not corrugate satisfactorily at 1 lb./in. web tension.
[e]Composite for Mediums 1, 2, 3, and 7.

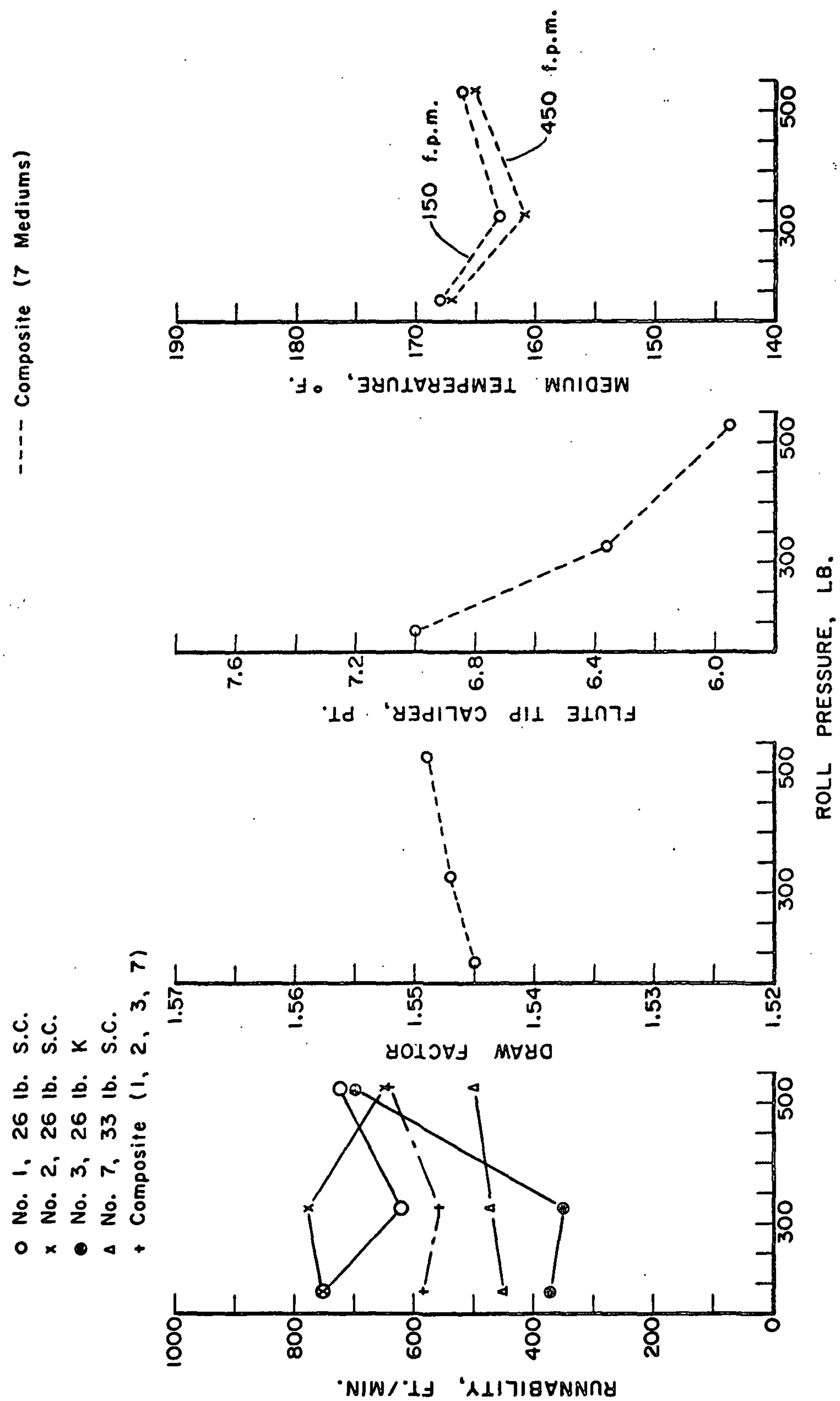


Figure 7. Effect of Roll Pressure on Runnability and Related Factors

kept in mind that because the data are limited and there is no replication, the analysis is probably not very sensitive. In fact, in this instance, the differences in runnability between mediums were not significant at the 0.05 level though they were significant at the 0.10 level.

The draw factors at maximum runnability speed exhibited slight increases with increasing roll pressure, on the average; however, the changes were not statistically significant at the 0.05 level. Increasing roll pressure markedly decreased flute tip calipers as would be anticipated and the changes were statistically significant at the 0.01 level.

Changes in roll pressure would not affect the temperature of the medium prior to its entrance into the corrugating nip; therefore, the variations in temperature should be regarded as arising from normal operational and measurement variability.

## EFFECT OF ROLL PARALLELISM

To evaluate the effects of roll parallelism on runnability, the main bearing supporting the upper corrugating roll was rotated to give two degrees of nonparallelism. In one case the bearing cam was rotated 3/32 inch from its "normal" position and, in the other case, the bearing cam was rotated 3/16 inch from its "normal" position. Pressure patterns indicated the flute side-wall pressures were essentially uniform across the roll width with the cam in its normal position. Offsetting the cam gave higher side-wall pressure on one side of the roll. It should be kept in mind that the roll width on the Institute's corrugator is 14 inches and the distance between bearings is about 36 inches. Therefore, the degree of nonparallelism achieved may be more severe than would be possible on a wider commercial single-facer.

TABLE XIV

STATISTICAL ANALYSIS OF THE EFFECT
OF ROLL PRESSURE ON RUNNABILITY

| Source of Variance | Degrees of Freedom | Mean Square | $F$ |
|---|---|---|---|
| | Runnability[c] | | |
| Between roll pressures | 2 | 8,125 | 0.62 |
| Between mediums | 3 | 56,719 | 4.32 |
| Residual error | 6 | 13,125 | |
| | Draw Factor | | |
| Between roll pressures | 2 | 0.0000215 | 1.57 |
| Between mediums | 6 | 0.0004335 | 3.17[b] |
| Residual error | 12 | 0.0000137 | |
| | Flute Tip Caliper | | |
| Between roll pressures[d] | 2 | 18.3412 | 29.25[a] |
| Between mediums[d] | 6 | 16.8275 | 296.26[a] |
| Interaction | 12 | 0.6271 | 11.04[a] |
| Residual error | 189 | 0.0568 | |
| | Temperature (150 f.p.m.) | | |
| Between roll pressures | 2 | 51.570 | 2.78 |
| Between mediums | 6 | 154.715 | 8.33[a] |
| Residual error | 12 | 18.572 | |

[a]Significant at the 0.01 level.

[b]Significant at the 0.05 level.

[c]Analysis restricted to Medium Samples 1, 2, 3, and 7.

[d]Roll pressure was considered to be a fixed factor; therefore, its mean square was compared to the interaction mean square. Medium sample was considered a random factor; therefore, its mean square was compared to the residual error.

The results obtained are summarized in Table XV. For the conditions employed it may be noted that the runnability remained constant for all three degrees of parallelism when the bogus medium was evaluated: The runnability for the kraft medium decreased in going from "normal" to 3/32 inch out of parallel and then remained constant. In the case of the semichemical medium the runnability at 3/32 inch out of parallel was lower than for the normal condition while at 3/16 inch out of parallel, the runnability was slightly higher than for the normal condition. Taken as a whole, the degrees of nonparallelism employed in this study did not affect runnability in a consistent pattern.

With regard to the draw factor, it may be noted that running with nonparallel rolls had little or no effect on draw. Also, the flute tip calipers exhibited no consistent trend to increase or decrease with changes in nonparallelism.

## EFFECT OF MOISTURE CONTENT OF MEDIUM

As originally proposed, it was planned to obtain mediums from one manufacturer made at five levels of moisture content from essentially the same furnish. Moisture content levels ranging from about 2-1/2 to 15% were desired. Because of difficulties in manufacture, this phase of the program was curtailed. Three rolls of medium were supplied to the Institute with moisture contents of 1.7, 4.3, and 20.0% (ovendry). The latter two rolls were manufactured on October 10 and 19, 1967, and the date of manufacture was not supplied for the 1.7% moisture content roll. Thus, the dates of manufacture were separated by at least nine days.

The results obtained are summarized in Table XVI and illustrated in Fig. 8. As may be noted the highest runnability was obtained with the roll having an initial moisture content of 4.3%. The lower runnability of the roll having an initial moisture content of 1.7% can, perhaps, be attributed to the fact that its

TABLE XV

EFFECT OF CORRUGATING ROLL PARALLELISM ON RUNNABILITY

| | Medium No. 1 - 26 lb. S.C.[a] (Roll 30) | Medium No. 4 - 26 lb. K.[a] (Roll 146) | Medium No. 6 - 26 lb. B.[a] (Roll 90) |
|---|---|---|---|
| Runnability, ft./min.[b] | | | |
| Normal roll parallelism | 700 | 1000[d] | 900 |
| 3/32-In. bearing adjustment out of parallel | 600 | 900 | 900 |
| 3/16-In. bearing adjustment out of parallel | 725 | 900 | 900 |
| Draw factor,[c] | | | |
| Normal roll parallelism | 1.548 | 1.539 | 1.534 |
| 3/32-In. bearing adjustment out of parallel | 1.548 | 1.539 | 1.535 |
| 3/16-In. bearing adjustment out of parallel | 1.546 | 1.538 | 1.542 |
| Flute tip caliper, pt.[c] | | | |
| Normal roll parallelism | 6.88 | 7.40 | 6.53 |
| 3/32-In. bearing adjustment out of parallel | 6.93 | 7.05 | 6.70 |
| 3/16-In. bearing adjustment out of parallel | 6.89 | 7.39 | 6.63 |

[a]S.C. = semichemical; K = kraft; B = bogus.

[b]Evaluated at 1 lb./in. web tension.

[c]Measured at runnability speed.

[d]Corrugated satisfactorily at maximum speed employed in this study.

TABLE XVI

EFFECT OF MEDIUM MOISTURE CONTENT ON RUNNABILITY

| | Medium No. 8-26-lb. Semichemical | Medium No. 9-26-lb. Semichemical | Medium No. 10-26-lb. Semichemical |
|---|---|---|---|
| Moisture content, % | 1.7 | 4.3 | 20.0 |
| Date of manufacture | --[c] | 10-10-67 | 10-19-67 |
| Runnability, f.p.m.[a] | 450 | 725 | 600 |
| Draw factor: | | | |
| 150 f.p.m. | 1.569 | 1.570 | 1.568 |
| 300 f.p.m. | 1.570 | 1.571 | 1.562 |
| 450 f.p.m. | 1.569 | 1.565 | 1.550 |
| 600 f.p.m. | -- | 1.563 | 1.539 |
| 725 f.p.m. | -- | 1.558 | -- |
| Average: | 1.569 | 1.565 | 1.555 |
| Flute tip caliper, pt.[b] | 7.38 | 7.10 | 6.61 |
| Medium temperature, °F. | | | |
| 150 f.p.m. | 194 | 178 | 157 |
| 300 f.p.m. | 200 | 178 | 160 |
| 450 f.p.m. | 198 | 177 | 157 |
| 600 f.p.m. | 192 | 171 | 153 |
| 750 f.p.m. | 190 | 166 | 143 |
| 900 f.p.m. | 178 | 160 | 137 |
| 1000 f.p.m. | -- | 154 | -- |

[a] Evaluated using 1 lb./in. web tension.

[b] Measured at runnability speed.

[c] No manufacturing date.

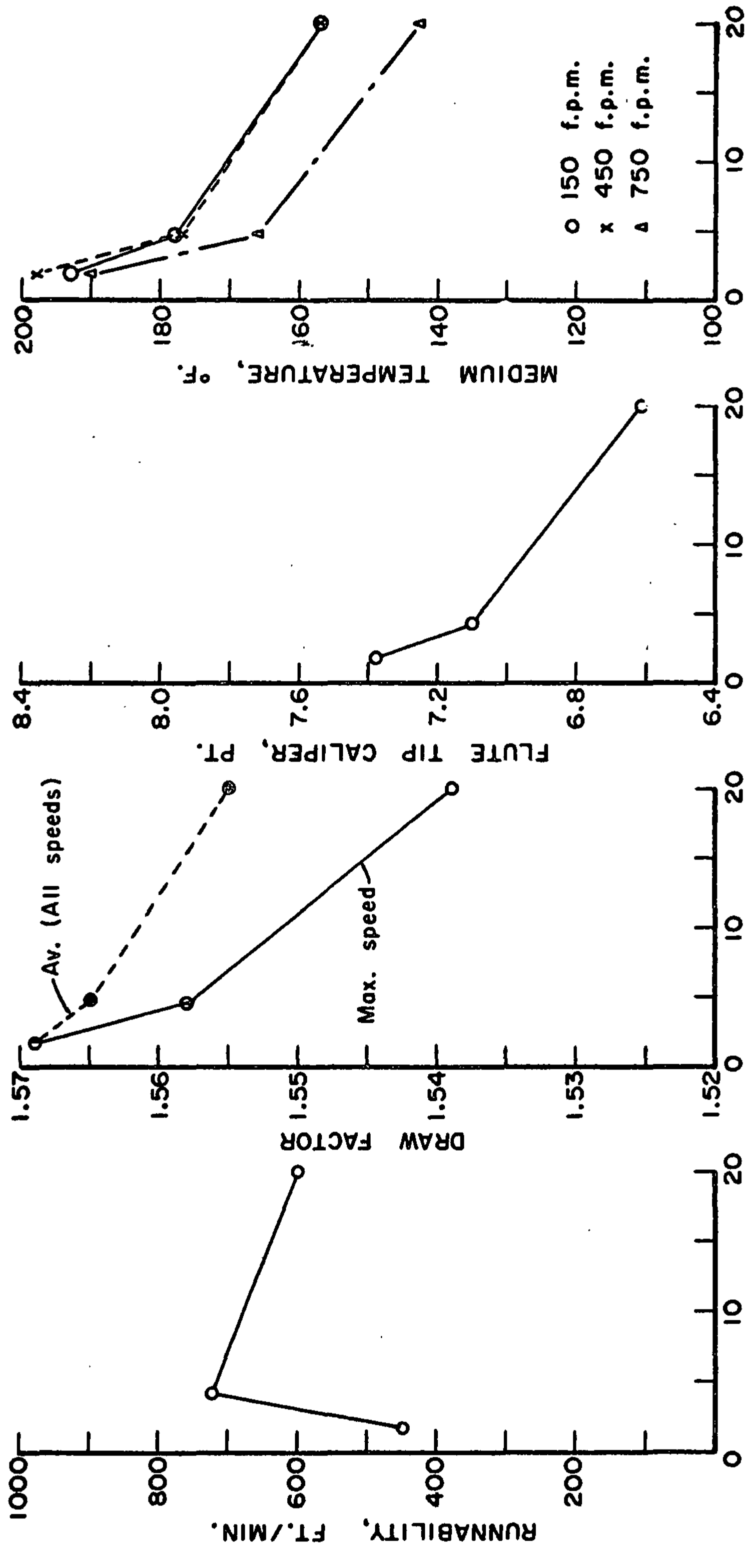


Figure 8. Effect of Moisture Content of Medium on Runnability and Related Characteristics

allowable stretch would be very low due to the low moisture content. This could cause fracturing of the medium at lower speeds than would be the case when the initial moisture content level is in a more normal range. The lower runnability of the medium having the high initial moisture content perhaps occurs because the coefficient of friction may be higher due to (1) the higher moisture content, and (2) lower temperature of the sheet entering the nip. If the coefficient of friction is higher for the more moist, cooler sheet, this would result in higher tension forces and cause fracture.

The above remarks are speculative to a considerable extent because normal manufacturing variations — furnish, paper machine, etc. — could certainly cause changes as great as those observed. The separation of the real effects from those associated with material and measurement variations would require controlled manufacture of the medium and proper replications. The latter is necessary to obtain an estimate of the experimental error against which the significance of the effects of interest may be assessed.

It may be noted that both the average draw factor and the draw factor at maximum speed tended to decrease with increasing moisture content. The same held true for the flute tip caliper measurements indicating a greater permanent loss in caliper at the higher moisture content. Medium temperatures entering the nip were markedly affected by the initial moisture content.

## EFFECT OF ANGLE OF TAKE-OFF

In one phase of the study, the angle of take-off of the single-faced board was varied because of its possible effect on high-low corrugations. In general, varying the angle of take-off should not affect medium fracturing, draw factor, or flute tip caliper. However, as a matter of completeness, the runnability evaluations were also carried out in connection with the corrugator trials directed toward studying high-low corrugations.

As may be noted in Table XVII, the changes in runnability speed followed no consistent pattern. The statistical analysis shown in Table XVIII indicates that the runnability changes with angle of take-off were not statistically significant at the 0.05 level. Therefore, it is believed the variations in runnability should be regarded as being caused by normal process and material variability.

As expected, neither the draw factors nor the flute tip calipers exhibited a consistent trend with angle of take-off and it is believed the differences obtained were associated with normal variability.

## EFFECT OF WEB ORIENTATION

Runnability trials were carried out by feeding the medium web into the corrugating labyrinth in two ways, namely, (1) wire side down, and (2) wire side up. When the wire side was down, the wire side was bonded to the single-face liner, and vice versa. The runnability results are summarized in Table XIX. As may be noted, lower runnabilities were obtained with the wire side down orientation for two of the mediums while the bogus medium ran satisfactorily at 1000 f.p.m. for both web orientations. In the forming operation it would be anticipated that the stresses imposed on the web would be essentially the same regardless of orientation. On this basis it would be expected that the runnability would be about the same for the two orientations. On the other hand, there are fewer fines on the wire side of the sheet. This might cause differences in runnability if the impacts of the teeth on the bottom roll resulted in different strain levels in the medium depending on which side was being impacted.

The differences in draw, flute tip caliper, and temperature were small and are probably not significant in terms of process and measurement variability.

TABLE XVII

EFFECT OF ANGLE OF TAKE-OFF ON RUNNABILITY

| | Sample No. 1 - 26 lb. S.C.[a] (Roll 30) | Sample No. 4 - 26 lb. K.[a] (Roll 146) | Sample No. 6 - 26 lb. B.[a] (Roll 90) | Average |
|---|---|---|---|---|
| Runnability, f.p.m.[b] | | | | |
| Angle of take-off -- 15° low | 600 | 850 | 900 | 783 |
| Angle of take-off -- tangential | 700 | 900 | 900 | 833 |
| Angle of take-off -- 15° high | 600 | 900 | 825 | 775 |
| Draw factor[c] | | | | |
| Angle of take-off -- 15° low | 1.549 | 1.540 | 1.534 | 1.541 |
| Angle of take-off -- tangential | 1.548 | 1.550 | 1.534 | 1.544 |
| Angle of take-off -- 15° high | 1.545 | 1.539 | 1.533 | 1.539 |
| Flute tip caliper, pt.[c] | | | | |
| Angle of take-off -- 15° low | 7.18 | 7.27 | 6.66 | 7.04 |
| Angle of take-off -- tangential | 6.88 | 7.23 | 6.53 | 6.88 |
| Angle of take-off -- 15° high | 7.01 | 7.35 | 6.73 | 7.03 |

[a]S.C. = semichemical; K = kraft; B = bogus.

[b]Evaluated at 1 lb./in. tension.

[c]Measured at runnability speed.

TABLE XVIII

STATISTICAL ANALYSIS OF THE EFFECT OF ANGLE OF TAKE-OFF ON RUNNABILITY AND DRAW

| Source of Variance | Degrees of Freedom | Mean Square | F |
|---|---|---|---|
| **Runnability** | | | |
| Between angles of take-off | 2 | 2,986.1 | 1.95 |
| Between mediums | 2 | 60,486.1 | 39.59[a] |
| Residual error | 4 | 1,527.8 | |
| **Draw Factor** | | | |
| Between angles of take-off | 2 | 0.0000195 | 1.73 |
| Between mediums | 2 | 0.0001465 | 13.02[a] |
| Residual error | 4 | 0.0000112 | |

[a]Significant at the 0.01 level.

## RELATIONSHIPS BETWEEN RUNNABILITY AND THE PHYSICAL CHARACTERISTICS OF THE MEDIUM

As discussed previously, the major strains imposed in the medium in the corrugating operation appear to be those associated with web tension, bending, shear, and transverse compression. Based on present understanding of the phenomena involved, it is hypothesized that medium runnability may depend on the following characteristics: (1) coefficient of friction, (2) critical bending strain, (3) critical shear strain, (4) transverse compression characteristics, and (5) caliper. Unfortunately, it is not possible, at present, to properly evaluate certain of the above characteristics.

With the above in mind, the mediums evaluated for runnability in this study were characterized in terms of weight, caliper, tensile, and stretch. Also, their transverse compression characteristics and coefficients of friction (medium vs. chromed steel) were evaluated at 73°F. and 300°F. Two types of transverse bonding tests were performed, namely: (1) the z-direction tensile test, and (2) the IGT

TABLE XIX

EFFECT OF WEB ORIENTATION ON RUNNABILITY

| | Medium No. 1 - 26 Lb. S.C.[a] (Roll 29) | Medium No. 4 - 26 Lb. K.[a] (Roll 145) | Medium No. 5 - 26 Lb. B.[a] (Roll 85) |
|---|---|---|---|
| Runnability, f.p.m.[b] | | | |
| Wire side down[d] | 750 | 575 | 1000[e] |
| Wire side up[d] | 625 | 350 | 1000[e] |
| Draw factor[c] | | | |
| Wire side down[d] | 1.550 | 1.561 | 1.555 |
| Wire side up[d] | 1.548 | 1.559 | 1.555 |
| Flute tip caliper, pt.[c] | | | |
| Wire side down[d] | 6.03 | 6.07 | 6.25 |
| Wire side up[d] | 6.09 | 6.12 | 6.29 |
| Medium temperature, °F. | | | |
| 150 f.p.m.: | | | |
| Wire side down[d] | 163 | 176 | 178 |
| Wire side up[d] | 165 | 170 | 173 |
| 450 f.p.m.: | | | |
| Wire side down[d] | 158 | 175 | 175 |
| Wire side up[d] | 161 | 166 | 173 |

[a]S.C. = semichemical; K = kraft; B = bogus.

[b]Mediums 1 and 6 were evaluated at 1 lb./in. web tension; however, Medium 4 was evaluated at minimum (0.25 lb./in.) web tension because it could not be satisfactorily corrugated at 1 lb./in. web tension.

[c]Measured at runnability speed.

[d]When the wire side was down, the wire side was bonded to the single-face liner, and vice versa.

[e]Corrugated satisfactorily at the maximum speed employed in this study.

fiber pick test with the thought that these bonding tests might be related to the shear characteristics of the medium. In addition, the mediums were also characterized in terms of Concora flat crush, impulse (a high rate type of tension test) and their edgewise compression strength.

Because this study was directed toward evaluating the effects of various corrugating operational variables on runnability, there are insufficient data to permit more than a limited comparison of runnability with the physical characteristics of the medium. For this purpose the runnabilities of the 26-lb. mediums were ranked from low (1) to high (6) utilizing the data from the four following phases of the study: (1) web tension, (2) steam showers, (3) amount of preheat, and (4) roll pressure. The rankings are shown in Table XX. This procedure has the advantage of averaging out the variations in runnability from run-to-run and roll-to-roll.

TABLE XX

RUNNABILITY RANKINGS OF 26-LB. CORRUGATING MEDIUMS

| Sample No. | Rank[a] Web Tension, lb./in. 0.25 | 1.0 | 2.0 | Shower Pressure, p.s.i. 0 | 14 | 28 | Preheater Wrap None | Half | Full | Roll Pressure, lb./in. 187 | 327 | 513 | Av. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4.5 | 2.5 | 1.5 | 2 | 2 | 2 | 2.5 | 2.5 | 2 | 3.5 | 2 | 3 | 2.5 |
| 2 | 2 | 2.5 | 3 | 3 | 3 | 3.5 | 2.5 | 2.5 | 3 | 3.5 | 3 | 2 | 2.8 |
| 3 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1[b] | 1.0 |
| 4 | 4.5 | 5 | 5 | 4 | 5 | 5.5 | 5 | 5.5 | 5 | 2 | 5 | 4 | 4.6 |
| 5 | 4.5 | 5 | 6 | 5.5 | 5 | 5.5 | 6 | 5.5 | 5 | 5.5 | 5 | 5.5 | 5.3 |
| 6 | 4.5 | 5 | 4 | 5.5 | 5 | 3.5 | 4 | 4 | 5 | 5.5 | 5 | 5.5 | 4.7 |

[a]Ranked from low (1) to high (6).

[b]Assigned Rank 1 because it was necessary to use 0.25 instead of 1.0 lb./in. web tension to obtain runnabilities in excess of 150 f.p.m.

The average rankings from Table XX are graphically compared with a number of the medium characteristics in Fig. 9 and 10. As may be noted, none of the properties taken individually is well related to the runnability rankings though rough trends may be noted in some instances – e.g., caliper loss at 2000 p.s.i. This probably reflects an inability to properly measure the properties of the medium which govern runnability. In addition, runnability, no doubt, depends on several characteristics of the medium in which case multiple correlation techniques should be helpful. However, the data of this study are too limited to justify multiple correlation techniques.

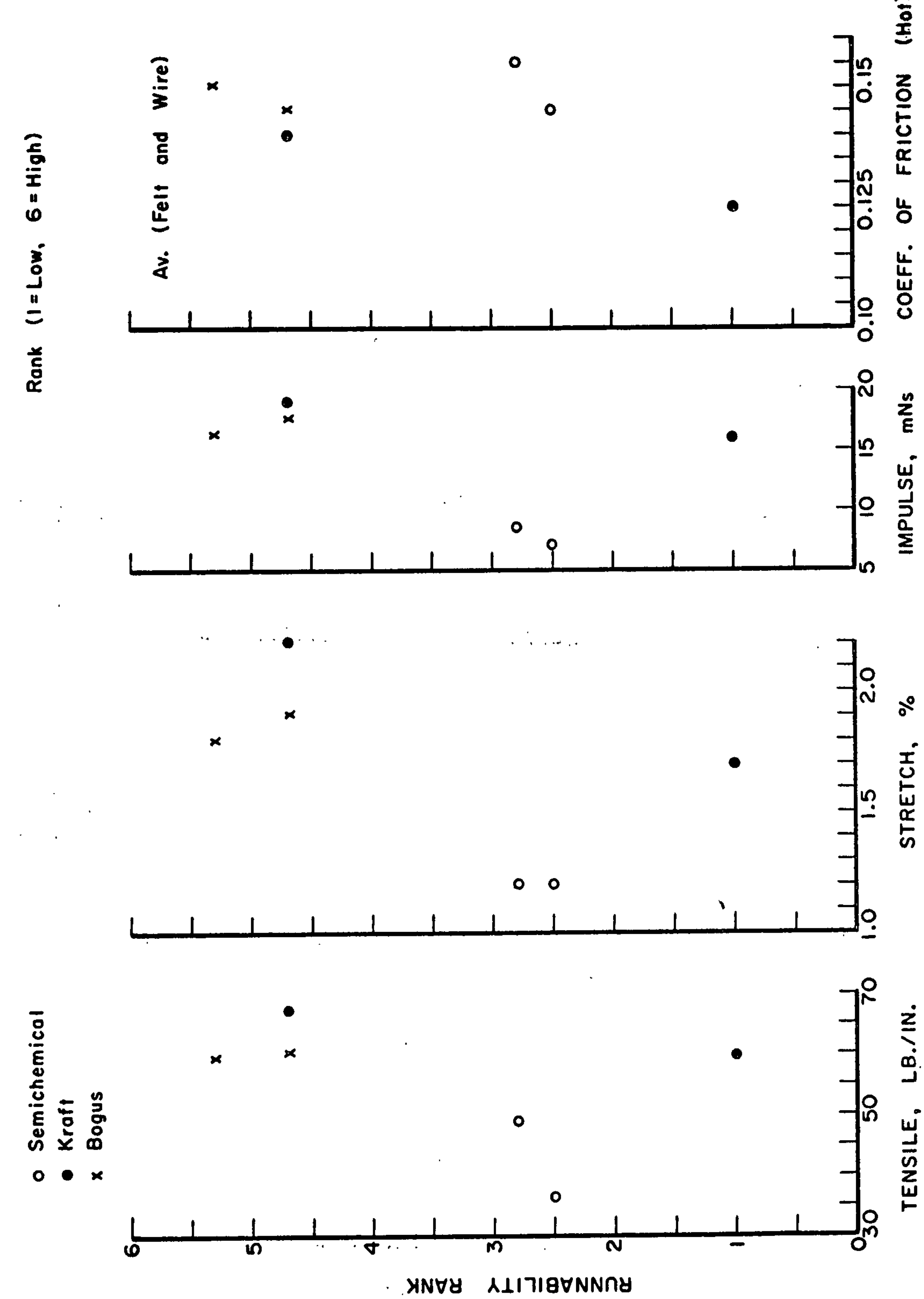


Figure 9. Relationship Between Runnability Rankings and Various Properties of the Medium

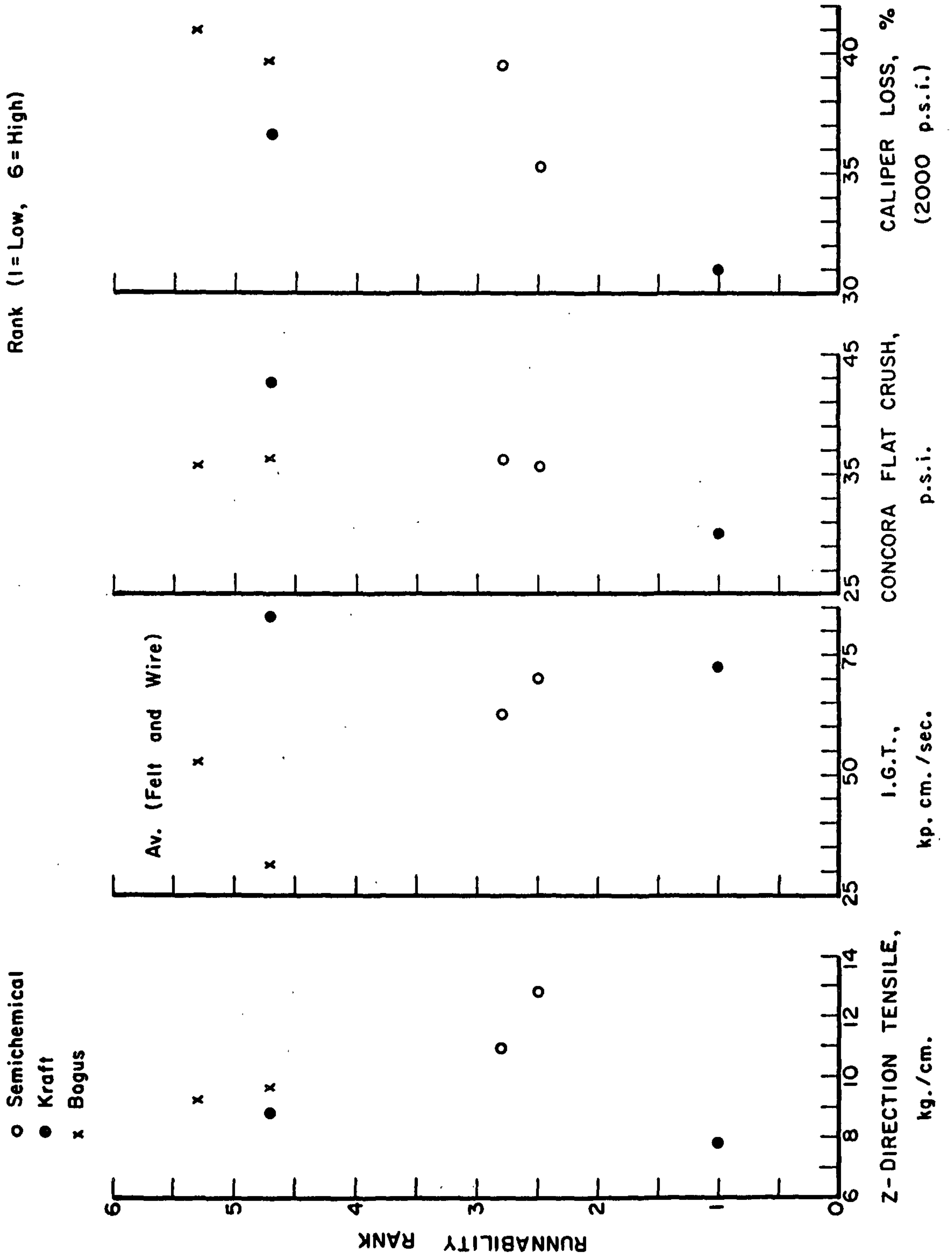


Figure 10. Relationship Between Runnability Rankings and Various Properties of the Corrugating Medium

# REVIEW OF LITERATURE ON HIGH-LOW CORRUGATIONS

## EFFECT OF OPERATIONAL VARIABLES

### Corrugating Speed

In a study at the Institute (33), sixteen commercially produced A-, B-, and C-flute single-faced boards were evaluated to determine the height of consecutive flutes. It was observed that the heights of consecutive flutes were usually alternately high and low — i.e., there was a periodic variation in flute height. This behavior was manifested by all the boards examined. In another study, McKee (6) noted that these periodic patterns were present in single-faced board produced on the Institute's corrugator. The average difference in caliper of consecutive flutes increased rapidly as the critical runnability speed was approached and varied in magnitude for the different mediums employed.

In a third study at the Institute (34), two semichemical mediums were evaluated for the occurrence of high-low corrugations at two speeds (30 and 600 ft./min.). High-low corrugations were found at both speeds but the fluctuations in height of consecutive flutes were greater at the higher speed. When a silicone spray (to reduce friction) was applied to the medium, it was observed that the fluctuations in height of consecutive flutes decreased in magnitude. In addition, 4.5 pt. aluminum foil was also evaluated at 30 ft./min., higher speeds not being possible because the foil fractured. Even in this case, a moderate degree of periodicity in height of consecutive flutes was observed.

### Web Tension

In a paper presented at the 1952 TAPPI Corrugating Conference, Scordas (35) presented a resumé of answers to a combiner questionnaire distributed by the

Corrugated Containers Committee. One section of this questionnaire asked the respondents for recommendations on ways of eliminating high-low corrugations. One of the answers given was proper adjustment of brake and roll tension. Other answers were also given and will be referred to later under the appropriate operational factors.

Results obtained at the Institute by means of high-speed photography (36) indicate that there is no visual evidence that high-low corrugations are present in the corrugating labyrinth or that they are formed by "pulling out" flutes which have already been formed. There is some evidence, however, that, on emerging from the corrugating labyrinth, all flutes do not bottom completely.

## Temperature of Corrugating Rolls

The necessity of adequate heating of the medium to promote its formability has been noted previously. In a study at the Institute previously referred to (18), the statement is made that increasing corrugator roll temperature promotes better flute formation, either by relieving the stresses and strains imposed by the corrugating operation or by increasing the allowable stresses and strains in the medium or by a combination of these factors. The same study also concluded that caliper of the single-faced board tends to increase as the temperature of the corrugating rolls increased and that the average and maximum differences in the heights of consecutive flutes tended to decrease under the same conditions. Skiver (37) has also noted that roll temperatures can contribute to the formation of high-low corrugations. Other requirements noted by Skiver are mediums with proper moisture level, caliper, and absence of foreign materials; rolls of medium wound at uniform tension; adequate showers and means for applying uniform pressure at the single-facer; and operators trained to compensate for any variables which are not satisfactory.

In the replies to a combiner questionnaire, Scordas (35) noted that the respondents listed inadequate heat transfer on the single-facer as a cause of high-low corrugations.

Use of Steam Showers

Magnuson (22) has stated that with increased steam pressures now in use, frequently the steam being used on showers is too dry. When this dry steam is applied to a dry medium, there may not be enough moisture to condition the medium or even to overcome the hydrophobic nature of the dry surface. The author indicates that under this condition and high machine speeds, the formation of high-low corrugations is almost inevitable.

Parallelism of Rolls

In his resumé of replies to a combiner questionnaire previously referred to in this survey, Scordas (35) points out that one of the reasons reported by the converters for high-low corrugations is nonparallel corrugating rolls.

Finger Arrangement

The effects of finger-type and clearance on high-low corrugations has been a matter of concern in the industry for many years. For example, Scordas (35) noted that various respondents to the combiner questionnaire recommended keeping the fingers "as close as possible to the corrugating roll" to reduce or eliminate high-low corrugations. Peters (38), an associate of the Peters Corrugated Machinery Co., states that the presence of the alternating high-low flutes is due to the finger arrangement.

Limited studies have been made at the Institute to evaluate the effect of (1) finger clearance with and without relief, (2) finger clearance at pressure roll nip and labyrinth, and (3) transfer roll clearance (39). Varying the finger clearance from 0.006 to 0.080 inch did not appear to have a significant effect on high-low corrugations for the semichemical or bogus mediums employed in the study. In the case of the kraft medium, the smaller clearances appeared better. Varying the clearance at the pressure roll did not appear to have any marked effect on the formation of high-low corrugations or caliper. When the amounts of relief in the fingers were varied there also was no marked trend for the caliper differences to change systematically with change in finger relief. Changes in clearance at the labyrinth or the transfer roll clearance also had no consistent effect on high-lows. In summarizing, it was remarked that the effects of finger design and clearance on the dimensional characteristics of the flute were far less than had been anticipated.

Roll Pressures

The upper corrugating roll is capable of rotational and also of translational motion parallel to a line joining the centers of the upper and lower corrugating rolls. This "up and down" motion has been called "drop action" and was described by Wilson (28). Peters (19) has also published work describing the same movement of the upper corrugating roll which he indicates amounts to 4 to 8/10,000th of an inch. Peters discusses qualitatively the possible effect of this motion. He indicates that it appears reasonable to conclude that this movement in the upper corrugating roll may produce variations in the molding force. Such variations, he concludes, may be expected to permit variations in the degree of "spring-back" of the flute arches when the medium leaves the corrugating labyrinth and, hence, may be contributory to the formation of high-low corrugations.

With the advent of stronger, stiffer mediums, there has been a trend to the use of heavier top roll pressure; consequently, greater roll crowns are required.

For example, where the crown was 0.012 to 0.013 in. on the old style mediums, the new medium requires 0.018 to 0.019 in. crown on the rolls. Running the old, more flexible medium on the rolls with higher crowns has resulted in greater abundance of high-low corrugations (40).

Flute Contour

Peters (19) discusses the effect of flute contour on high-low corrugations. He states that flute contour profiles with various degrees of clearance between the flanks of the teeth were studied by means of high-speed photography. For those profiles which allowed too much space he found that the pressure between the corrugating rolls was borne only by the flute tips resulting in the formation of high-low corrugations. Peters also notes that, in addition to the usual forming pressure in the labyrinth, the corrugating rolls move up and down, imparting a stress analogous to the blow of a hammer during each unrolling of a tooth. In modern machines, he indicates, this effect is counteracted by the use of elastic pressure devices designed to maintain constant pressure on the medium and to minimize the tendency of the rolls to move up and down.

Wilson's (26) comments relative to flute contour were previously summarized. With regard to high-low corrugations, Wilson notes that in addition to flute contour, the quality of the corrugating medium and certain operational variables influence high-lows.

Wilson also comments that symmetry of flute formation is important to high flat crush and caliper and that leaning, unsymmetrical corrugations (which reduce flat crush and caliper) can result from poor flute design. Generally, however, Wilson believes that improper mechanical adjustments are the cause — specifically, roll misalignment, worn bearings, insufficient loading, improper finger settings, etc.

Rolls that are unable to bottom properly or have excessive draw tension may draw paper from a previously formed flute, enough to shorten one side, thereby creating a leaning flute.

In 1953, Werner (41) published a fundamental discussion of flute contours. He, like Wilson, pointed out that flute contours with considerable clearance on the sides were associated with reduced high-low corrugations (more uniform board caliper) and higher flat crush.

Angle of Take-Off

Based on high-speed photographs taken at the Institute, there is no visual evidence that high-low corrugations are present in the corrugating labyrinth or are formed by "pulling out" flutes which have already been formed as has been suggested by others (36). There is some evidence in the same photographs that on emerging from the corrugating labyrinth all flutes do not bottom the same amount. In addition, the photographic evidence obtained in connection with the high-speed photography of the behavior of the medium during the corrugating operation has shown that after the fluff-out point the fingers force the fluted medium into better mesh with the bottom corrugating roll than existed prior to the fluff-out point. The foregoing is, of course, based on visual examination by side or edge viewing of the medium. There is a question as to whether the edge necessarily represents the behavior removed from the edge and also whether the eye is capable of detecting the small differences actually encountered in high-low corrugations.

Because of the foregoing and the rotation which the flutes undergo at the pressure nip, a study was undertaken at the Institute to investigate the state of stress and strain to which the medium is subjected during its passage through the pressure roll nip as it may affect high-low corrugations (42). It was noted that two major activities take place at the pressure nip, namely, (a) formation of the union between the flute tip and the single-face liner, and (b) the transition of the flutes from a state of rotary motion to linear motion. When the medium flutes are in mesh with the flutes of the bottom corrugating roll, the distance between consecutive flute tips is greater than the corresponding difference between the roots or valleys of the same flutes by an amount proportional to the difference in their radii. When the board emerges from the pressure roll nip in the form of single-faced board, however, the distances between flute tips and flute roots are equal. In order to compensate for the dimensional change it is necessary for the flutes to rotate so as to equalize the initial disparity in the distances between flute tips and roots. It was felt that possibly the rotation coupled with the direction of take-off or discharge, i.e., tangentially (at right angle to the line of centers of the two rolls), or a few degrees up or down from tangential, might have a marked effect on the formation of high-low corrugations.

As noted in Reference (42) high-speed photographs were taken to study the behavior at (a) entrance to the pressure roll nip, (b) in the pressure roll nip, and (c) leaving the pressure roll nip. Three angles of take-off were studied, namely, (1) tangential to pressure roll nip, (2) 15° high, and (3) 15° low. The relative speed of the pressure roll to bottom corrugating roll was also varied. The photographs indicated that the fluted medium drops off the end of the finger and is momentarily suspended in mid-air. It was observed that the distances which the flute drops follow, in many instances, a regular pattern with frequent reversals — i.e., successive flutes tend to drop in an alternate pattern of large and small amounts. In some instances it was possible to associate an excessive drop-off with a large difference in flute height of the two flutes involved. Based on the photographs and measurements of flute height for the one medium studied, it appeared that high-low corrugations were less pronounced when the take-off was 15° below normal.

## EFFECT OF MATERIAL VARIABLES

Velarde (43), Skiver (37), Scordas (35), and Wilson (26) have all stressed the importance of proper moisture content of the medium in order to obtain uniform molding of flutes and to eliminate, thereby, the occurrence of high-low corrugations. Velarde indicates that high-low corrugations are minimum when a medium has a moisture content of 6 to 7.5%. Scordas reports, in connection with the combiner questionnaire previously referred to in this report, that all converters completing the questionnaire agreed that, by increasing moisture content of the medium, the frequency of occurrence of high-low corrugations was reduced. They also indicated that kraft and bogus mediums were more prone to exhibit high-low corrugations than semichemical mediums.

Relative to the quality of the medium, Wilson (26) indicates that uneven formation creates areas in the web which shrink at different rates and create local cockling. He also indicates that excessive moisture may limit speeds and contribute to warpage while insufficient moisture may prevent proper forming of the flutes. Wilson notes that fugitive rosins or other sizes may cause the medium to stick to the corrugating rolls — perhaps contributing to high-low formation.

## DISCUSSION OF HIGH-LOW RESULTS

### EFFECT OF WEB TENSION

As in the case of runnability, the effects of web tension on high-low corrugations were studied at three tension levels, namely, 0.25, 1.0, and 2.0 lb./in. Single-faced board samples were obtained at a series of speeds (usually 150 ft./min. increments) up to the maximum runnability speed or 1000 ft./min. for each medium sample. The single-faced board samples were subsequently evaluated to determine the flute height and flute height uniformity.

The results obtained are summarized in Table XXI. Two measures of flute height are shown, namely (1) single-face caliper, and (2) average caliper of the individual flutes. As mentioned previously, single-face caliper was obtained by using a 0.020-inch shim to bridge across several flutes and utilized the usual Cady micrometer caliper (foot pressure, 7 to 9 p.s.i.). The individual flute height measurements were made using a special dial micrometer with a low foot pressure of 100 grams. Because of the difference in foot pressure, the individual flute height averages are generally higher than the single-face caliper averages. However, they are fairly well correlated. For this reason when flute height is referred to in the following pages, it will refer to the average caliper of the individual flutes.

Three measures of flute height uniformity are reported. They are:

1. Average difference in height of consecutive flutes.
2. Maximum difference in height of consecutive flutes.
3. Percentage of flute height differences in three ranges, namely, 0-3.0, 0-4.0, 0-5.0 points. These ranges were selected somewhat arbitrarily in the belief that flute height differences much greater than 4 or 5 points might result in high-lows at the double-backer.

TABLE XXI

EFFECT OF WEB TENSION ON HIGH-LOW CORRUGATIONS

| Medium Identification | | | Corr. | Single-Face Caliper, pt. | | | Individual Flute Caliper | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Av. Caliper, pt. | | | Av. Diff., pt. | | | Max. Diff., pt. | | | Cumulative Percentage of Differences in Flute Height, % | | | | | | | | |
| | | | | | | | | | | | | | | | | 0 - 3.0 pt. | | | 0 - 4.0 pt. | | | 0 - 5.0 pt. | | |
| | | Roll | Speed, | Tension, lb. | | | Tension, lb. | | | Tension, lb. | | | Tension, lb. | | | Tension, lb. | | | Tension, lb. | | | Tension, lb. | | |
| No. | Type[a] | No. | ft./min. | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 | 0.25 | 1.0 | 2.0 |
| 1 | 26-Lb. S.C. | 28 | 150 | -- | -- | 190.9 | -- | -- | 193.8 | -- | -- | 1.38 | -- | -- | 5.5 | -- | -- | 90.0 | -- | -- | 97.5 | -- | -- | 97.5 |
| | | | 175 | -- | -- | 190.3 | -- | -- | 193.3 | -- | -- | 1.72 | -- | -- | 9.0 | -- | -- | 85.0 | -- | -- | 95.0 | -- | -- | 95.0 |
| | | | 200 | -- | -- | 190.8 | -- | -- | 193.6 | -- | -- | 1.45 | -- | -- | 4.1 | -- | -- | 95.0 | -- | -- | 97.5 | -- | -- | 100.0 |
| | | | 300 | 193.0 | 191.2 | -- | 195.9 | 194.2 | -- | 2.00 | 2.00 | -- | 4.4 | 5.6 | -- | 80.0 | 82.5 | -- | 97.5 | 95.0 | -- | 100.0 | 95.0 | -- |
| | | | 450 | 192.6 | 191.0 | -- | 196.0 | 194.4 | -- | 2.26 | 1.58 | -- | 5.0 | 4.0 | -- | 72.5 | 90.0 | -- | 92.5 | 100.0 | -- | 100.0 | 100.0 | -- |
| | | | 600 | 193.2 | 190.0 | -- | 196.2 | 194.6 | -- | 2.16 | 2.88 | -- | 5.8 | 6.5 | -- | 77.5 | 57.5 | -- | 92.5 | 67.5 | -- | 95.0 | 87.5 | -- |
| | | | 900 | -- | 190.3 | -- | -- | 194.5 | -- | -- | 3.50 | -- | -- | 9.8 | -- | -- | 57.5 | -- | -- | 70.0 | -- | -- | 75.0 | -- |
| | | | 1000 | 192.5 | -- | -- | 195.9 | -- | -- | 3.16 | -- | -- | 8.2 | -- | -- | 55.0 | -- | -- | 67.5 | -- | -- | 80.0 | -- | -- |
| | | | Av. | 192.8 | 190.6 | 190.7 | 196.0 | 194.4 | 193.6 | 2.40 | 2.49 | 1.52 | | | | | | | | | | | | |
| 2 | 26-Lb. S.C. | 59 | 300 | 193.1 | 192.0 | 191.3 | 195.7 | 194.4 | 193.7 | 2.45 | 3.02 | 2.74 | 5.8 | 8.8 | 7.5 | 67.5 | 57.5 | 62.5 | 77.5 | 75.0 | 77.5 | 92.5 | 82.5 | 85.0 |
| | | | 450 | 193.0 | 192.1 | 190.4 | 195.0 | 194.1 | 192.9 | 2.46 | 3.10 | 2.07 | 5.5 | 7.0 | 7.0 | 62.5 | 50.0 | 77.5 | 82.5 | 67.5 | 87.5 | 95.0 | 80.0 | 92.5 |
| | | | 600 | 192.7 | 191.8 | 190.8 | 195.0 | 194.4 | 192.7 | 2.98 | 3.92 | 4.43 | 6.8 | 7.1 | 12.0 | 47.5 | 30.0 | 37.5 | 72.5 | 50.0 | 50.0 | 97.5 | 72.5 | 62.5 |
| | | | 725 | -- | -- | 191.4 | -- | -- | 193.1 | -- | -- | 4.51 | -- | -- | 16.3 | -- | -- | 52.5 | -- | -- | 60.0 | -- | -- | 60.0 |
| | | | 900 | -- | 190.9 | -- | -- | 194.0 | -- | -- | 5.64 | -- | -- | 15.0 | -- | -- | 30.0 | -- | -- | 42.5 | -- | -- | 45.0 | -- |
| | | | 950 | 191.4 | -- | -- | 193.7 | -- | -- | 6.26 | -- | -- | 16.5 | -- | -- | 27.5 | -- | -- | 35.0 | -- | -- | 42.5 | -- | -- |
| | | | Av. | 192.6 | 191.7 | 191.0 | 194.8 | 194.2 | 193.1 | 3.54 | 3.92 | 3.44 | | | | | | | | | | | | |
| 3 | 26-Lb. K | 46 | 150 | 191.3 | 191.2 | 190.5 | 194.2 | 193.3 | 193.2 | 3.16 | 3.93 | 3.32 | 7.6 | 9.0 | 9.1 | 57.5 | 42.5 | 57.5 | 62.5 | 52.5 | 67.5 | 67.5 | 67.5 | 72.5 |
| | | | 175 | -- | -- | 191.1 | -- | -- | 193.4 | -- | -- | 4.56 | -- | -- | 11.7 | -- | -- | 32.5 | -- | -- | 47.5 | -- | -- | 57.5 |
| | | | 200 | -- | 191.5 | 190.7 | -- | 193.6 | 192.5 | -- | 2.12 | 3.03 | -- | 8.1 | 7.5 | -- | 70.0 | 52.5 | -- | 85.0 | 67.5 | -- | 95.0 | 80.0 |
| | | | 250 | -- | 191.5 | -- | -- | 193.8 | -- | -- | 3.74 | -- | -- | 10.5 | -- | -- | 55.0 | -- | -- | 62.5 | -- | -- | 70.0 | -- |
| | | | 275 | -- | 190.9 | -- | -- | 193.5 | -- | -- | 4.50 | -- | -- | 10.1 | -- | -- | 42.5 | -- | -- | 47.5 | -- | -- | 55.0 | -- |
| | | | 300 | 191.8 | -- | -- | 194.5 | -- | -- | 3.04 | -- | -- | 7.5 | -- | -- | 65.0 | -- | -- | 67.5 | -- | -- | 77.5 | -- | -- |
| | | | 450 | 190.4 | -- | -- | 193.5 | -- | -- | 2.56 | -- | -- | 8.0 | -- | -- | 72.5 | -- | -- | 77.5 | -- | -- | 82.5 | -- | -- |
| | | | Av. | 191.2 | 191.3 | 190.8 | 194.1 | 193.6 | 193.0 | 2.92 | 3.59 | 2.73 | | | | | | | | | | | | |
| 4 | 26-Lb. K | 144 | 300 | 195.7 | 194.4 | 194.3 | 197.5 | 195.9 | 196.2 | 2.16 | 2.53 | 2.68 | 4.5 | 6.6 | 7.5 | 77.5 | 65.0 | 65.0 | 92.5 | 75.0 | 67.5 | 100.0 | 92.5 | 77.5 |
| | | | 450 | 196.0 | 194.6 | 194.0 | 197.7 | 196.3 | 196.3 | 2.10 | 2.41 | 2.82 | 6.0 | 7.7 | 11.3 | 72.5 | 70.0 | 60.0 | 92.5 | 82.5 | 77.5 | 95.0 | 90.0 | 85.0 |
| | | | 600 | 196.7 | 194.8 | 193.5 | 198.5 | 196.4 | 196.0 | 2.35 | 3.35 | 5.15 | 5.4 | 8.9 | 12.2 | 70.0 | 55.0 | 30.0 | 82.5 | 70.0 | 42.5 | 97.5 | 82.5 | 47.5 |
| | | | 925 | -- | -- | 194.3 | -- | -- | 196.7 | --- | -- | 4.30 | -- | -- | 10.4 | -- | -- | 47.5 | -- | -- | 50.0 | -- | -- | 60.0 |
| | | | 1000 | 195.9 | 194.0 | -- | 197.6 | 196.1 | -- | 4.42 | 4.78 | -- | 13.5 | 11.5 | -- | 37.5 | 37.5 | -- | 57.5 | 45.0 | -- | 70.0 | 60.0 | -- |
| | | | Av. | 196.1 | 194.4 | 194.0 | 197.8 | 196.2 | 196.3 | 2.76 | 3.27 | 3.74 | | | | | | | | | | | | |
| 5 | 26-Lb. B | 84 | 300 | 193.5 | 191.6 | 191.7 | 195.6 | 194.0 | 193.8 | 1.82 | 1.74 | 1.25 | 6.2 | 4.7 | 3.8 | 82.5 | 82.5 | 92.5 | 97.5 | 97.5 | 100.0 | 97.5 | 100.0 | 100.0 |
| | | | 450 | 192.3 | 191.7 | 191.5 | 194.8 | 193.5 | 193.4 | 1.36 | 1.47 | 1.36 | 4.6 | 3.1 | 3.5 | 95.0 | 97.5 | 97.5 | 97.5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | | | 600 | 192.8 | 191.5 | 190.8 | 195.4 | 193.7 | 193.2 | 1.74 | 1.89 | 1.87 | 4.7 | 4.7 | 7.3 | 85.0 | 80.0 | 85.0 | 95.0 | 90.0 | 90.0 | 100.0 | 100.0 | 92.5 |
| | | | 1000 | 192.6 | 191.4 | 190.5 | 195.0 | 193.7 | 193.2 | 4.89 | 2.58 | 2.88 | 15.2 | 7.6 | 8.5 | 35.0 | 70.0 | 65.0 | 52.5 | 77.5 | 75.0 | 57.5 | 87.5 | 77.5 |
| | | | Av. | 192.8 | 191.6 | 191.1 | 195.2 | 193.7 | 193.4 | 2.45 | 1.92 | 1.84 | | | | | | | | | | | | |
| 6 | 26-Lb. B | 88 | 300 | 192.6 | 192.8 | 191.0 | 194.7 | 194.3 | 193.1 | 1.80 | 2.39 | 2.10 | 5.6 | 5.3 | 5.6 | 82.5 | 65.0 | 75.0 | 90.0 | 82.5 | 80.0 | 95.0 | 95.0 | 90.0 |
| | | | 450 | 191.5 | 191.0 | 189.4 | 193.8 | 192.6 | 191.7 | 3.26 | 2.49 | 2.33 | 9.0 | 7.7 | 6.5 | 50.0 | 65.0 | 60.0 | 62.5 | 82.5 | 80.0 | 75.0 | 90.0 | 92.5 |
| | | | 600 | 191.8 | 190.4 | 189.4 | 194.0 | 192.2 | 191.3 | 2.01 | 1.77 | 4.11 | 6.4 | 6.0 | 10.2 | 77.5 | 82.5 | 55.0 | 92.5 | 95.0 | 60.0 | 97.5 | 95.0 | 60.0 |
| | | | 775 | -- | -- | 190.0 | -- | -- | 191.7 | -- | -- | 3.50 | -- | -- | 12.2 | -- | -- | 57.5 | -- | -- | 67.5 | -- | -- | 75.0 |
| | | | 1000 | 191.1 | 189.7 | -- | 193.6 | 191.9 | -- | 5.05 | 4.05 | -- | 12.7 | 14.7 | -- | 30.0 | 47.5 | -- | 50.0 | 57.5 | -- | 57.5 | 62.5 | -- |
| | | | Av. | 191.8 | 191.0 | 190.0 | 194.0 | 192.8 | 192.0 | 3.03 | 2.68 | 3.01 | | | | | | | | | | | | |
| 7 | 33-Lb. S.C. | 148 | 150 | 194.0 | 193.9 | 192.6 | 194.8 | 194.6 | 194.0 | 0.95 | 0.93 | 0.90 | 2.2 | 2.6 | 2.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | | | 300 | 192.8 | 193.5 | 192.7 | 195.4 | 194.4 | 194.1 | 1.90 | 1.03 | 2.14 | 6.7 | 2.9 | 7.4 | 85.0 | 100.0 | 85.0 | 90.0 | 100.0 | 87.5 | 92.5 | 100.0 | 90.0 |
| | | | 375 | -- | -- | 192.4 | -- | -- | 193.6 | -- | -- | 2.44 | -- | -- | 6.0 | -- | -- | 75.0 | -- | -- | 80.0 | -- | -- | 87.5 |
| | | | 425 | -- | -- | 192.3 | -- | -- | 193.2 | -- | -- | 2.77 | -- | -- | 7.6 | -- | -- | 60.0 | -- | -- | 70.0 | -- | -- | 82.5 |
| | | | 450 | 193.8 | 192.5 | -- | 195.1 | 193.4 | -- | 1.48 | 1.47 | -- | 4.0 | 11.4 | -- | 92.5 | 92.5 | -- | 100.0 | 95.0 | -- | 100.0 | 97.5 | -- |
| | | | 475 | -- | 192.6 | -- | -- | 194.5 | -- | -- | 2.76 | -- | -- | 8.6 | -- | -- | 67.5 | -- | -- | 87.5 | -- | -- | 90.0 | -- |
| | | | 600 | 192.9 | -- | -- | 194.5 | -- | -- | 3.41 | -- | -- | 7.2 | -- | -- | 47.5 | -- | -- | 70.0 | -- | -- | 80.0 | -- | -- |
| | | | Av. | 193.4 | 193.1 | 192.5 | 195.0 | 194.2 | 193.7 | 1.94 | 1.55 | 2.06 | | | | | | | | | | | | |
| | Composite average: | | | 193.0 | 192.0 | 191.4 | 195.3 | 194.2 | 193.6 | 2.72 | 2.75 | 2.62 | | | | | | | | | | | | |

[a]S.C. = semichemical; K = kraft; B = Bogus.

In general, the higher the average difference, the more likely that high-low corrugations will be observed in the double-backing operation, assuming the variance of the individual height measurements remains constant or increases as the average increases.

Average Caliper Difference

In Fig. 11, the average caliper differences for the 26-lb. medium samples are plotted against speed for each tension level. As discussed in past work, it may be noted that the caliper differences generally appear to fluctuate about a low level plateau at the lower speeds and then increase in magnitude as the speed increases — particularly so as the maximum runnability speed is approached. It should be kept in mind that the maximum runnability speed generally decreases with increased tension.

It may be speculated that the effects of web tension on the average caliper difference might take one of the forms shown in Fig. 12. The four cases are discussed below:

1. Case 1: Tension has a marked effect on caliper differences and the curves are offset by equal amounts at all speeds. As illustrated, at maximum runnability, the caliper differences are essentially the same. However, it would be equally possible that the level of caliper differences at maximum speed could also vary with tension.

2. Case 2: Tension has only a small effect on caliper differences; however, the curves remain offset by a constant amount at all speeds. In this case it appears likely that the average caliper difference at the maximum runnability should decrease with increasing tension.

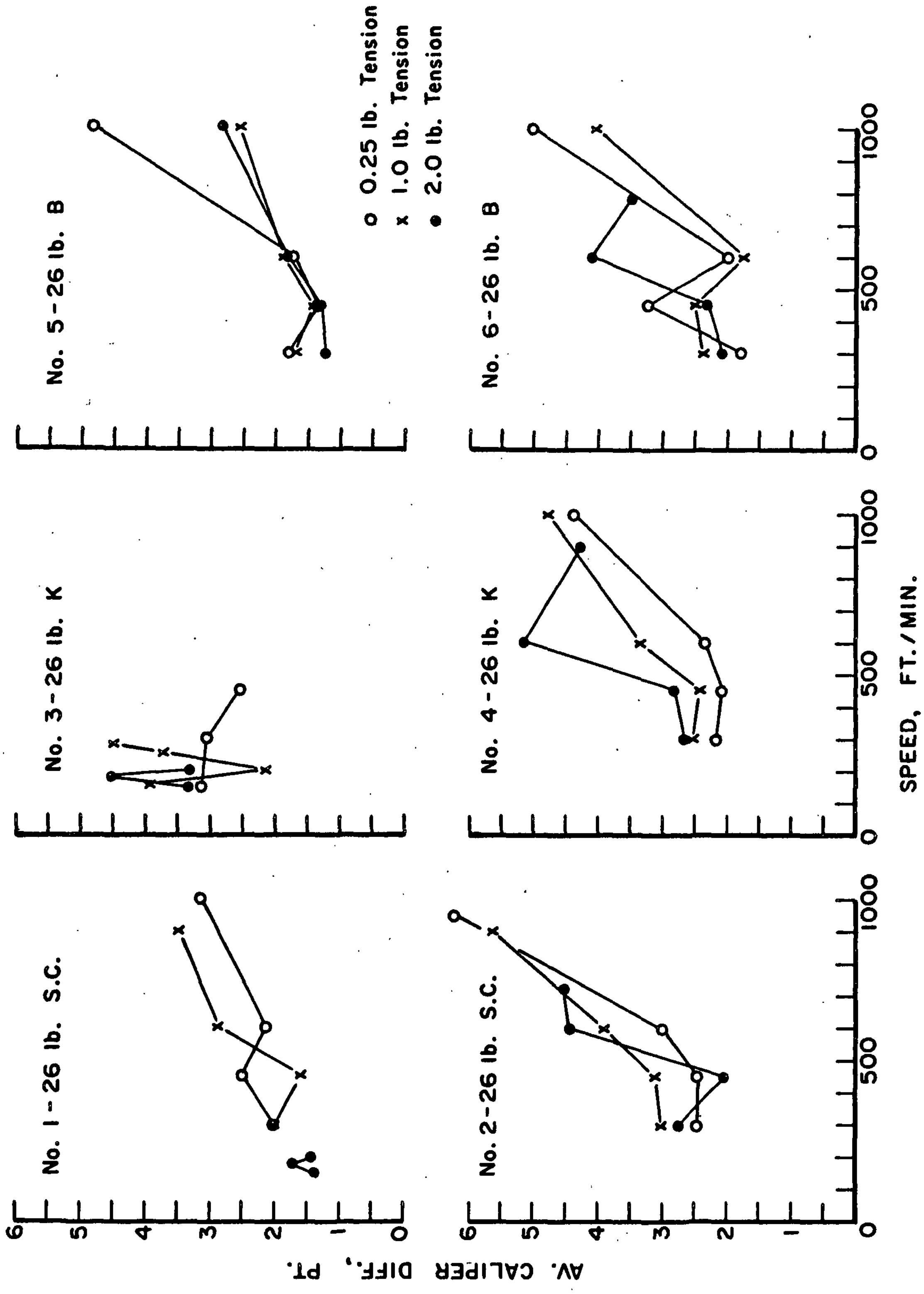


Figure 11. Effect of Speed and Tension on Average Caliper Difference

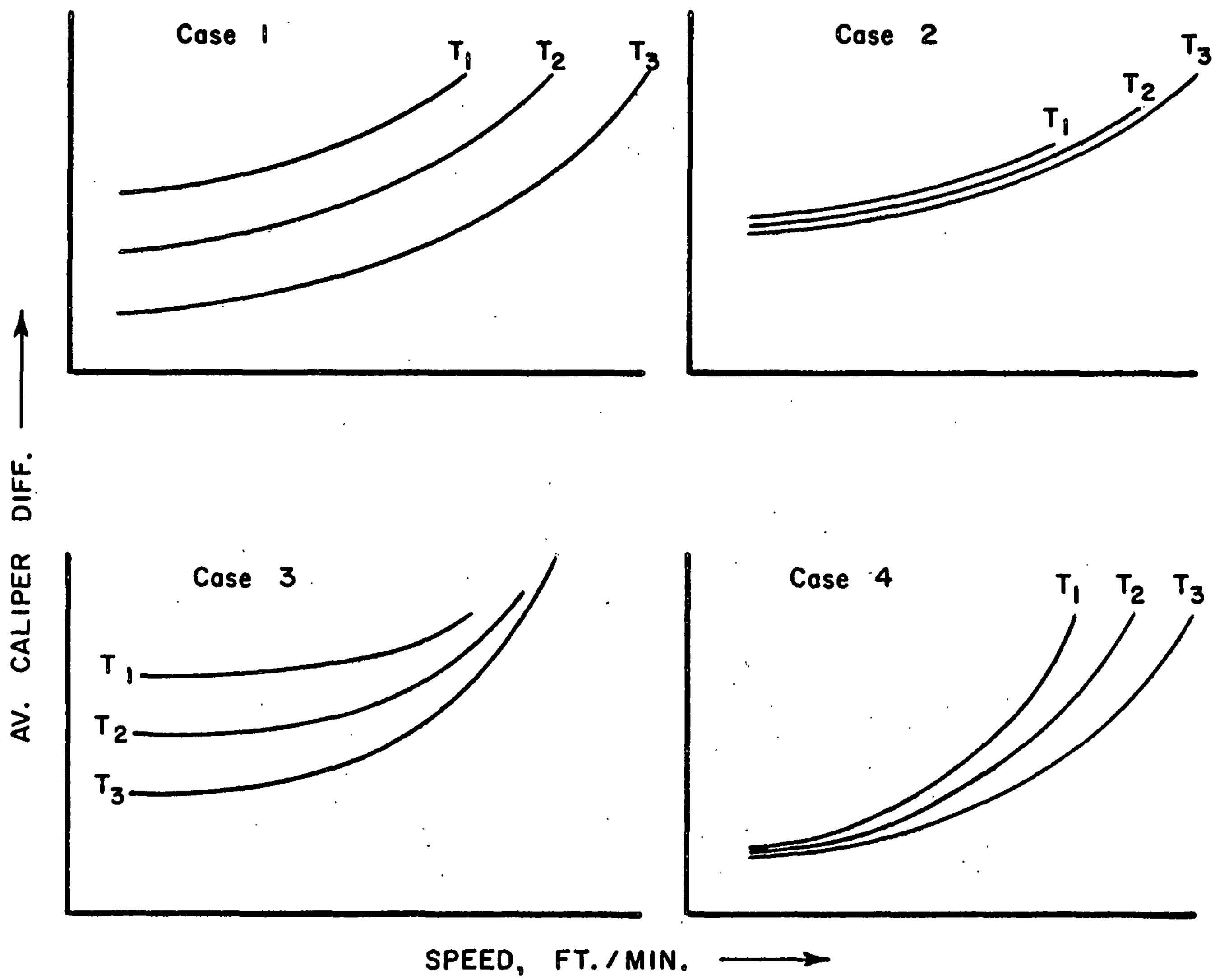


Figure 12. Idealized Relationships Between the Average Caliper Difference, Speed and Web Tension

3. Case 3: Tension has an appreciable effect on the caliper differences at low speeds but the curves tend to merge together at higher speeds. In this case the caliper differences at maximum runnability speed would probably decrease slightly with increasing tension.

4. Case 4: Tension has little effect at lower speeds, but the curves diverge at higher speeds. As illustrated, the caliper differences at maximum runnability speed are essentially equal. However, it would be equally possible that the level of caliper differences at maximum runnability could also vary with tension.

The erratic fluctuations in the data graphed in Fig. 11 make it difficult to conclude which case might be favored. Also, the fact that the maximum runnability speed was not reached in all cases is a complicating factor when considering caliper differences at maximum runnability. With these reservations, the fact that tension does not appear to have a consistent effect at low speeds tends to rule out Cases 1 and 3. There is perhaps, some suggestion that Case 4 represents the more likely situation.

To investigate the above in more detail, an analysis of variance was carried out using the data for those samples where results were available at all tension levels at speeds of 300, 450, and 600 ft./min. The data are retabulated in Table XXII and the analysis of variance is shown in Table XXIII. For this restricted range of speeds and samples it may be noted that web tension, by itself, was not significant at the 0.05 level; however, the tension x speed interaction was significant at the 0.01 level. This indicates that the effect of tension depends on the speed level and vice versa as illustrated in Fig. 13. In the figure, when caliper difference is plotted against web tension, the caliper differences at the 300 and 450 ft./min. are essentially constant and, judging by the 95% confidence interval (also shown on graph), the small differences between tension levels would not be statistically significant. At 600 ft./min., however, the caliper differences increase appreciably with increasing web tension. The contrasting trends at the different speeds give rise to the significant interaction between tension and speed. Therefore, this analysis indicates that increasing web tension may increase the incidence of high-low corrugations but its effect will be most evident at the higher speeds. Because speed and tension interact as shown in Figure 13, this also suggests that the idealized relationship shown in Case 4 of Fig. 12 probably best describes the effects of tension and speed on high-low corrugations.

TABLE XXII

SUMMARY OF DATA USED IN ANALYSIS OF THE EFFECT OF WEB TENSION ON HIGH-LOW CORRUGATIONS

| Medium No. | Speed, ft./min. | Average Caliper Diff., pt. Web Tension, lb./in. 0.25 | 1.0 | 2.0 | Composite |
|---|---|---|---|---|---|
| 2 | 300 | 2.45 | 3.02 | 2.74 | |
| | 450 | 2.46 | 3.10 | 2.07 | 3.02 |
| | 600 | 2.98 | 3.92 | 4.43 | |
| 4 | 300 | 2.16 | 2.53 | 2.68 | |
| | 450 | 2.10 | 2.41 | 2.82 | 2.84 |
| | 600 | 2.35 | 3.35 | 5.15 | |
| 5 | 300 | 1.82 | 1.74 | 1.25 | |
| | 450 | 1.36 | 1.47 | 1.36 | 1.61 |
| | 600 | 1.74 | 1.89 | 1.87 | |
| 6 | 300 | 1.80 | 2.39 | 2.10 | |
| | 450 | 3.26 | 2.49 | 2.33 | 2.47 |
| | 600 | 2.01 | 1.77 | 4.11 | |
| Average: | 300 | 2.06 | 2.42 | 2.19 | 2.22 |
| | 450 | 2.30 | 2.37 | 2.14 | 2.27 |
| | 600 | 2.27 | 2.73 | 3.89 | 2.96 |
| Composite average: | | 2.21 | 2.51 | 2.74 | |

TABLE XXIII

ANALYSIS OF VARIANCE OF AVERAGE CALIPER DIFFERENCES
AS AFFECTED BY SPEED AND WEB TENSION

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | $F$ | Components of Variance |
|---|---|---|---|---|---|
| Between tensions ($T$) | Fixed | 2 | 0.8627 | 2.04 | $\sigma_o^2 + 3\ \sigma_{MT}^2 + 12\ \sigma_T^2$ |
| Between mediums ($M$) | Random | 3 | 3.5223 | 21.83[b] | $\sigma_o^2 + 9\ \sigma_M^2$ |
| Between speeds ($S$) | Fixed | 2 | 2.0679 | 5.75[a] | $\sigma_o^2 + 3\ \sigma_{MS}^2 + 12\ \sigma_S^2$ |
| $T$ x $M$ interaction | -- | 6 | 0.4220 | 2.62 | $\sigma_o^2 + 3\ \sigma_{TM}^2$ |
| $M$ x $S$ interaction | -- | 6 | 0.3596 | 2.23 | $\sigma_o^2 + 3\ \sigma_{MS}^2$ |
| $T$ x $S$ interaction | -- | 4 | 1.0542 | 6.53[a] | $\sigma_o^2 + 4\ \sigma_{TS}^2$ |
| Residual | -- | 12 | 0.1614 | | $\sigma_o^2$ |

[a]Significant at the 0.05 level.
[b]Significant at the 0.01 level.

The analysis of variance also indicated that speed by itself was a significant factor which is in accord with previous experience. It should be kept in mind that the analysis was restricted to speeds less than 600 ft./min. As a result, the generally higher caliper differences at maximum runnability were omitted from the analysis. If included, the statistical significance of speed as a factor in high-low corrugations would, no doubt, become even more apparent.

With regard to mediums, the analysis indicated that the differences between the four samples were highly significant. The composite caliper difference averages for the four medium samples are shown below:

| | Av. Caliper Difference, pt. |
|---|---|
| Medium 2 | 3.02 |
| Medium 4 | 2.84 |
| Medium 5 | 1.61 |
| Medium 6 | 2.47 |

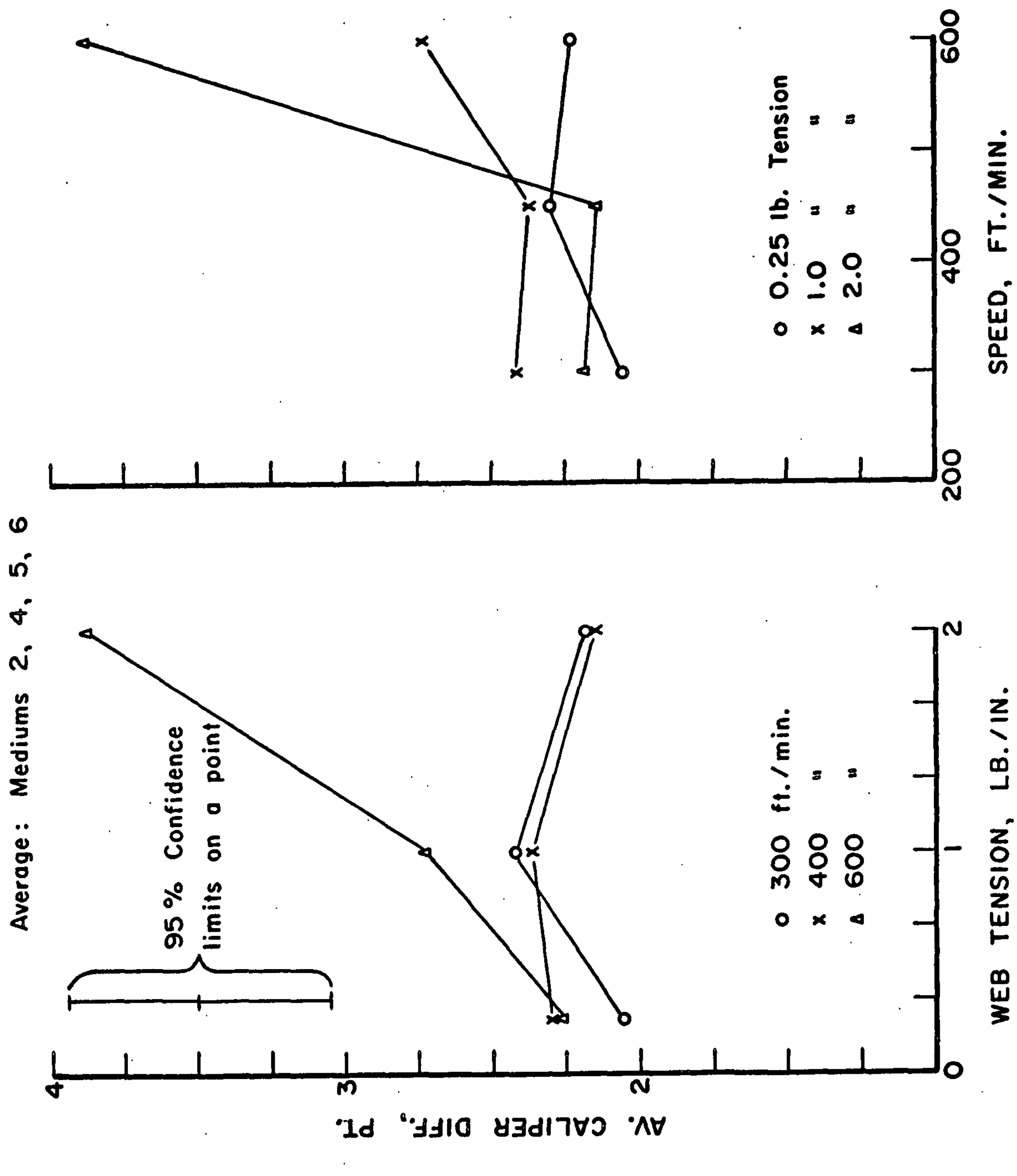


Figure 13. The Effect of Web Tension and Speed Interactions on the Average Caliper Difference

In view of the fact that the 95% confidence interval for the composite averages equals ± 0.29 point, it appears likely that Medium 5 is significantly lower than Medium 6 and possibly Medium 6 is significantly lower than Medium 2. It should be cautioned that the data are too limited to draw conclusions relative to type of medium (semichemical, bogus, kraft) with regard to their tendency to form high-low corrugations.

Average Flute Height

An analysis similar to the above was carried out for flute height (average caliper of individual flutes). The data used are summarized in Table XXIV and the analysis of variance is shown in Table XXV. It may be noted that the effects of tension on flute height were highly significant. As illustrated in Fig. 14, increasing tension slightly, but significantly, decreased flute height. In this case there was also a significant interaction between tension and medium indicating that the effect of tension was somewhat dependent on the medium. The interaction is illustrated in Fig. 14 where it may be noted that for two of the mediums there was little change in flute height in going from 1 to 2 lb./in. tension.

The analysis also indicated that the differences in flute height between mediums were highly significant. Speed by itself, was not a significant factor; however, a speed x medium interaction was significant. As illustrated in Fig. 14, it appears that, for this restricted range of speeds and mediums, flute height tended to decrease with increasing speed; however, exceptions occurred giving rise to the significant interaction.

EFFECT OF SHOWER PRESSURE

As in the case of runnability, the effects of the steam showers on flute height uniformity were studied at three levels of steam pressure, namely, 0 (no shower),

TABLE XXIV

SUMMARY OF DATA USED IN ANALYSIS OF THE EFFECT OF WEB TENSION ON FLUTE HEIGHT

| Medium No. | Speed, ft./min. | Average Caliper, pt. Web Tension, lb./in. 0.25 | 1.0 | 2.0 | Composites | |
|---|---|---|---|---|---|---|
| 2 | 300 | 195.7 | 194.4 | 193.7 | 194.6 | 194.2 |
| | 450 | 195.0 | 194.1 | 192.9 | 194.0 | |
| | 600 | 195.0 | 194.4 | 192.7 | 194.0 | |
| | Av. | 195.2 | 194.3 | 193.1 | | |
| 4 | 300 | 197.5 | 195.9 | 196.2 | 196.5 | 196.8 |
| | 450 | 197.7 | 196.3 | 196.3 | 196.8 | |
| | 600 | 198.5 | 196.4 | 196.0 | 197.0 | |
| | Av. | 197.9 | 196.2 | 196.2 | | |
| 5 | 300 | 195.6 | 194.0 | 193.8 | 194.5 | 194.2 |
| | 450 | 194.8 | 193.5 | 193.4 | 193.9 | |
| | 600 | 195.4 | 193.7 | 193.2 | 194.1 | |
| | Av. | 195.3 | 193.7 | 193.5 | | |
| 6 | 300 | 194.7 | 194.3 | 193.1 | 194.0 | 193.1 |
| | 450 | 193.8 | 192.6 | 191.7 | 192.7 | |
| | 600 | 194.0 | 192.2 | 191.3 | 192.5 | |
| | Av. | 194.2 | 193.0 | 192.0 | | |
| Average: | 300 | 195.9 | 194.6 | 194.2 | 194.9 | -- |
| | 450 | 195.3 | 194.1 | 193.6 | 194.3 | -- |
| | 600 | 195.7 | 194.2 | 193.3 | 194.4 | -- |
| Composite average: | | 195.6 | 194.3 | 193.7 | | |

14 and 28 p.s.i. The results obtained are summarized in Table XXVI. The caliper differences were averaged over all speeds for each medium and the results are illustrated in Fig. 15. As may be noted, when shower pressures were increased from 0 (no shower) to 14 p.s.i., the caliper differences decreased for five of the six 26-lb. mediums. In the one exception, the caliper difference increased slightly in going from no shower to 14 p.s.i. shower pressure. No data were available for the 33-lb. medium using no shower because the medium was severely fractured even at a speed of 150 ft./min. When shower pressures were increased from 14 to 28 p.s.i., caliper differences increased in three instances, decreased in three instances and remained approximately the same in one instance.

TABLE XXV

ANALYSIS OF VARIANCE OF AVERAGE FLUTE HEIGHT
AS AFFECTED BY SPEED AND WEB TENSION

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | $\underline{F}$ | Components of Variance |
|---|---|---|---|---|---|
| Between tensions ($\underline{T}$) | Fixed | 2 | 11.8975 | 48.88[b] | $\sigma_o^2 + 3\,\sigma_{\underline{MT}}^2 + 12\,\sigma_{\underline{T}}^2$ |
| Between mediums ($\underline{M}$) | Random | 3 | 21.9070 | 347.68[b] | $\sigma_o^2 + 9\,\sigma_{\underline{M}}^2$ |
| Between speeds ($\underline{S}$) | Fixed | 2 | 1.1658 | 2.12 | $\sigma_o^2 + 3\,\sigma_{\underline{MS}}^2 + 12\,\sigma_{\underline{S}}^2$ |
| $\underline{T}$ x $\underline{M}$ interaction | -- | 6 | 0.2434 | 3.86[a] | $\sigma_o^2 + 3\,\sigma_{\underline{TM}}^2$ |
| $\underline{M}$ x $\underline{S}$ interaction | -- | 6 | 0.5495 | 8.72[b] | $\sigma_o^2 + 3\,\sigma_{\underline{MS}}^2$ |
| $\underline{T}$ x $\underline{S}$ interaction | -- | 4 | 0.1721 | 2.73 | $\sigma_o^2 + 4\,\sigma_{\underline{TS}}^2$ |
| Residual error | -- | 12 | 0.0630 | | $\sigma_o^2$ |

[a]Significant at the 0.05 level.

[b]Significant at the 0.01 level.

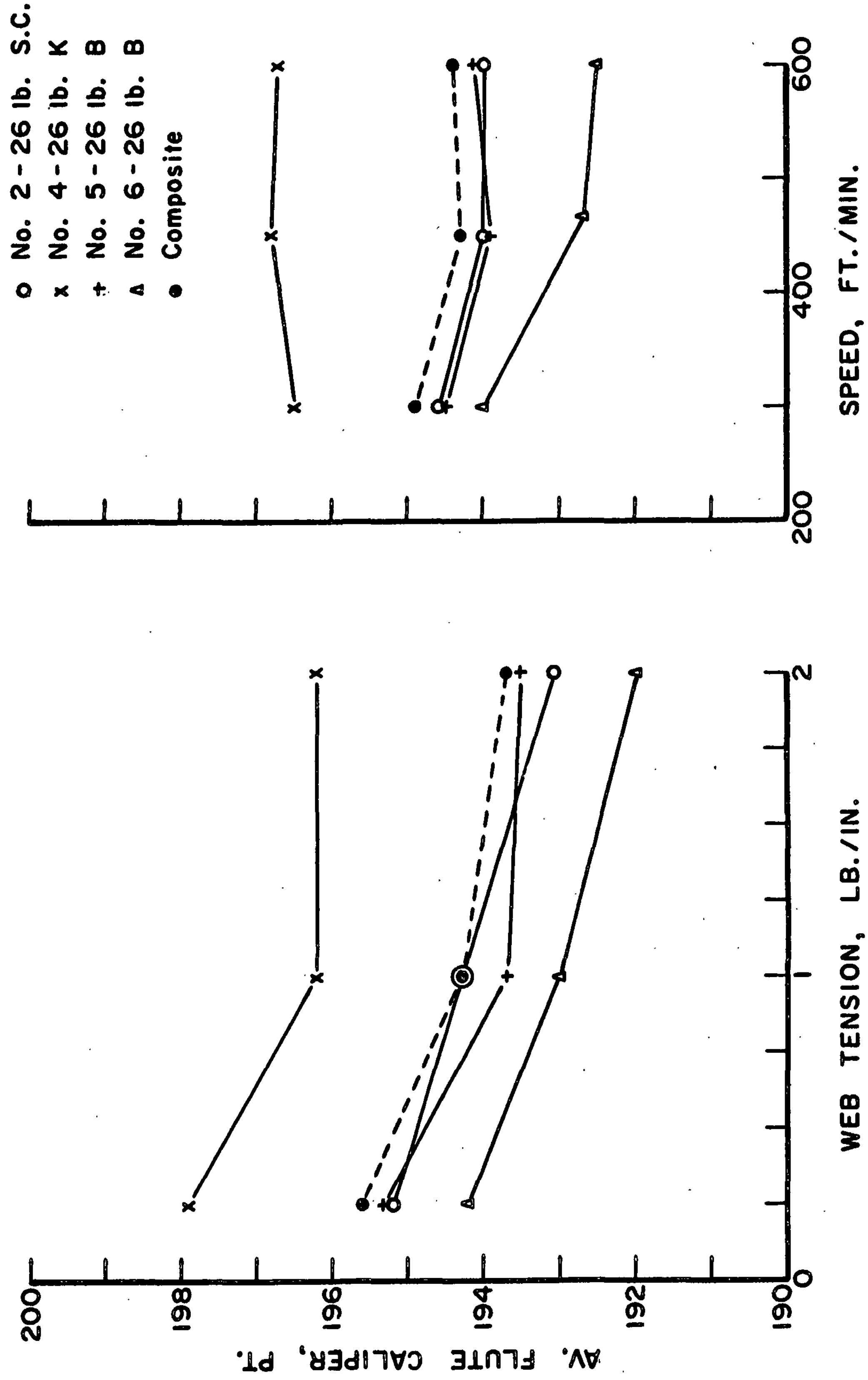


Figure 14. Effect of Web Tension and Speed on Flute Height

TABLE XXVI

EFFECT OF MEDIUM STEAM SHOWERS ON HIGH-LOW CORRUGATIONS

| Medium Identification | | | Corr. Speed, ft./min. | Single-Face Caliper, pt. | | | Individual Flute Caliper: Av. Caliper, pt. | | | Av. Diff., pt. | | | Max. Diff., pt. | | | Cumulative Percentages of Differences in Flute Height, %: 0 - 3.0 pt. | | | 0 - 4.0 pt. | | | 0 - 5.0 pt. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Shower Pressure, p.s.i. | | | Shower Pressure, p.s.i. | | | Shower Pressure, p.s.i. | | | Shower Pressure, p.s.i. | | | Shower Pressure, p.s.i. | | | Shower Pressure, p.s.i. | | | Shower Pressure, p.s.i. | | |
| No. | Type[a] | Roll No. | | 0 | 14 | 28 | 0 | 14 | 28 | 0 | 14 | 28 | 0 | 14 | 28 | 0 | 14 | 28 | 0 | 14 | 28 | 0 | 14 | 28 |
| 1 | 26-Lb. S.C. | 28 | 150 | 192.6 | 191.6 | 191.8 | 195.9 | 193.9 | 193.9 | 1.53 | 1.12 | 1.37 | 4.5 | 4.2 | 3.3 | 87.5 | 97.5 | 97.5 | 92.5 | 97.5 | 100.0 | 100.0 | 100.0 | 100.0 |
| | | | 300 | 192.6 | 191.6 | 191.2 | 195.2 | 194.3 | 193.6 | 2.95 | 2.64 | 1.89 | 6.6 | 7.6 | 4.8 | 50.0 | 65.0 | 75.0 | 70.0 | 77.5 | 90.0 | 92.5 | 85.0 | 100.0 |
| | | | 450 | 192.9 | 191.1 | 190.8 | 195.8 | 193.8 | 193.2 | 2.86 | 2.57 | 2.01 | 7.3 | 7.0 | 5.0 | 57.5 | 62.5 | 82.5 | 75.0 | 77.5 | 92.5 | 85.0 | 80.0 | 100.0 |
| | | | 600 | -- | 191.4 | 191.3 | -- | 194.0 | 193.5 | -- | 2.43 | 2.97 | -- | 6.3 | 8.4 | -- | 75.0 | 57.5 | -- | 80.0 | 70.0 | -- | 95.0 | 82.5 |
| | | | Av. | 192.7 | 191.4 | 191.3 | 195.6 | 194.0 | 193.6 | 2.45 | 2.19 | 2.06 | | | | | | | | | | | | |
| 2 | 26-Lb. S.C. | 59 | 150 | 191.3 | -- | -- | 194.8 | -- | -- | 2.58 | -- | -- | 7.0 | -- | -- | 70.0 | -- | -- | 77.5 | -- | -- | 80.0 | -- | -- |
| | | | 300 | 191.6 | 192.1 | 191.5 | 194.7 | 194.4 | 194.2 | 4.03 | 3.02 | 3.20 | 7.2 | 8.8 | 8.0 | 30.0 | 57.5 | 47.5 | 50.0 | 75.0 | 60.0 | 70.0 | 82.5 | 87.5 |
| | | | 450 | 191.7 | 192.1 | 190.7 | 194.3 | 194.1 | 193.5 | 4.17 | 3.10 | 2.58 | 10.5 | 7.0 | 7.0 | 35.0 | 50.0 | 62.5 | 50.0 | 67.5 | 82.5 | 60.0 | 80.0 | 85.0 |
| | | | 600 | 191.2 | 191.8 | 190.2 | 194.3 | 194.4 | 193.5 | 4.09 | 3.92 | 3.33 | 8.9 | 7.1 | 8.7 | 40.0 | 30.0 | 52.5 | 50.0 | 50.0 | 67.5 | 60.0 | 72.5 | 80.0 |
| | | | 900 | -- | 190.9 | 190.8 | -- | 194.0 | 193.3 | -- | 5.64 | 4.72 | -- | 15.0 | 12.3 | -- | 30.0 | 42.5 | -- | 42.5 | 50.0 | -- | 45.0 | 60.0 |
| | | | Av. | 191.4 | 191.7 | 190.8 | 194.5 | 194.2 | 193.6 | 3.72 | 3.92 | 3.46 | | | | | | | | | | | | |
| 3 | 26-Lb. K | 46 | 150 | 191.1 | 191.9 | 191.7 | 194.9 | 194.4 | 194.3 | 5.50 | 3.67 | 3.45 | 10.6 | 8.2 | 9.0 | 20.0 | 50.0 | 50.0 | 27.5 | 57.5 | 57.5 | 35.0 | 67.5 | 72.5 |
| | | | 175 | 191.4 | -- | -- | 194.8 | -- | -- | 4.86 | -- | -- | 10.8 | -- | -- | 32.5 | -- | -- | 45.0 | -- | -- | 52.5 | -- | -- |
| | | | 200 | 191.5 | 191.8 | -- | 194.8 | 194.1 | -- | 4.46 | 2.88 | -- | 11.0 | 6.8 | -- | 35.0 | 60.0 | -- | 47.5 | 72.5 | -- | 57.5 | 87.5 | -- |
| | | | 225 | 192.6 | -- | -- | 194.8 | -- | -- | 3.85 | -- | -- | 8.5 | -- | -- | 47.5 | -- | -- | 55.0 | -- | -- | 62.5 | -- | -- |
| | | | 275 | -- | 192.3 | -- | -- | 194.0 | -- | -- | 2.78 | -- | -- | 6.7 | -- | -- | 57.5 | -- | -- | 75.0 | -- | -- | 80.0 | -- |
| | | | 300 | -- | -- | 191.5 | -- | -- | 194.0 | -- | -- | 4.10 | -- | -- | 9.5 | -- | -- | 37.5 | -- | -- | 50.0 | -- | -- | 65.0 |
| | | | 325 | -- | 192.1 | -- | -- | 194.2 | -- | -- | 3.86 | -- | -- | 10.4 | -- | -- | 50.0 | -- | -- | 65.0 | -- | -- | 70.0 | -- |
| | | | 350 | -- | -- | 190.8 | -- | -- | 193.6 | -- | -- | 4.07 | -- | -- | 8.2 | -- | -- | 37.5 | -- | -- | 55.0 | -- | -- | 67.5 |
| | | | 375 | -- | -- | 190.2 | -- | -- | 193.0 | -- | -- | 3.61 | -- | -- | 12.3 | -- | -- | 52.5 | -- | -- | 67.5 | -- | -- | 75.0 |
| | | | Av. | 191.6 | 192.0 | 191.0 | 194.8 | 194.2 | 193.7 | 4.67 | 3.30 | 3.81 | | | | | | | | | | | | |
| 4 | 26-Lb. K | 144 | 300 | 196.0 | 194.4 | 195.3 | 198.2 | 195.9 | 197.0 | 2.54 | 2.53 | 1.35 | 5.6 | 6.6 | 4.2 | 57.5 | 65.0 | 95.0 | 82.5 | 75.0 | 97.5 | 92.5 | 92.5 | 100.0 |
| | | | 450 | 195.3 | 194.6 | 194.4 | 198.2 | 196.3 | 196.6 | 3.42 | 2.41 | 1.72 | 6.7 | 7.7 | 4.2 | 42.5 | 70.0 | 85.0 | 65.0 | 82.5 | 97.5 | 85.0 | 90.0 | 100.0 |
| | | | 600 | 195.8 | 194.8 | 195.0 | 198.8 | 196.4 | 197.2 | 2.96 | 3.35 | 2.26 | 9.0 | 8.9 | 7.8 | 57.5 | 55.0 | 70.0 | 77.5 | 70.0 | 85.0 | 85.0 | 82.5 | 90.0 |
| | | | 900 | 195.0 | -- | -- | 197.3 | -- | -- | 7.44 | -- | -- | 15.5 | -- | -- | 17.5 | -- | -- | 30.0 | -- | -- | 40.0 | -- | -- |
| | | | 1000 | -- | 194.0 | 194.6 | -- | 196.1 | 196.7 | -- | 4.78 | 3.54 | -- | 11.5 | 8.8 | -- | 37.5 | 47.5 | -- | 45.0 | 67.5 | -- | 60.0 | 77.5 |
| | | | Av. | 195.5 | 194.4 | 194.8 | 198.1 | 196.2 | 196.9 | 4.09 | 3.27 | 2.22 | | | | | | | | | | | | |
| 5 | 26-Lb. B | 84 | 300 | 193.7 | 191.6 | 193.0 | 196.2 | 194.0 | 194.8 | 1.70 | 1.74 | 1.62 | 5.3 | 4.7 | 5.7 | 82.5 | 82.5 | 90.0 | 95.0 | 97.5 | 95.0 | 97.5 | 100.0 | 97.5 |
| | | | 450 | 193.6 | 191.7 | 191.8 | 195.7 | 193.5 | 193.7 | 1.69 | 1.47 | 1.56 | 4.0 | 3.1 | 3.6 | 87.5 | 97.5 | 95.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | | | 600 | 193.4 | 191.5 | 192.0 | 196.3 | 193.7 | 194.0 | 2.31 | 1.89 | 2.60 | 6.4 | 4.7 | 7.5 | 67.5 | 80.0 | 60.0 | 80.0 | 90.0 | 82.5 | 92.5 | 100.0 | 90.0 |
| | | | 1000 | 193.1 | 191.4 | 191.5 | 196.2 | 193.7 | 193.4 | 3.56 | 2.58 | 1.85 | 8.9 | 7.6 | 4.5 | 52.5 | 70.0 | 72.5 | 57.5 | 77.5 | 92.5 | 80.0 | 87.5 | 100.0 |
| | | | Av. | 193.4 | 191.6 | 192.1 | 196.1 | 193.7 | 194.0 | 2.32 | 1.92 | 1.91 | | | | | | | | | | | | |
| 6 | 26-Lb. B | 88 | 300 | 193.0 | 192.8 | 191.3 | 195.8 | 194.3 | 193.3 | 3.53 | 2.39 | 2.52 | 8.0 | 5.3 | 6.4 | 40.0 | 65.0 | 62.5 | 65.0 | 82.5 | 82.5 | 80.0 | 95.0 | 90.0 |
| | | | 450 | 191.8 | 191.0 | 191.0 | 194.5 | 192.6 | 192.6 | 3.21 | 2.49 | 2.41 | 7.7 | 7.7 | 7.5 | 50.0 | 65.0 | 70.0 | 72.5 | 82.5 | 80.0 | 77.5 | 90.0 | 90.0 |
| | | | 600 | 192.6 | 190.4 | 189.8 | 195.2 | 192.2 | 191.7 | 3.39 | 1.77 | 2.92 | 10.7 | 6.0 | 7.4 | 50.0 | 82.5 | 65.0 | 62.5 | 95.0 | 70.0 | 72.5 | 95.0 | 80.0 |
| | | | 900 | -- | -- | 188.8 | -- | -- | 191.0 | -- | -- | 3.42 | -- | -- | 11.0 | -- | -- | 55.0 | -- | -- | 62.5 | -- | -- | 72.5 |
| | | | 1000 | 191.8 | 189.6 | -- | 194.5 | 191.9 | -- | 4.21 | 4.05 | -- | 14.0 | 14.7 | -- | 52.5 | 47.5 | -- | 67.5 | 57.5 | -- | 77.5 | 62.5 | -- |
| | | | Av. | 192.3 | 191.0 | 190.2 | 195.0 | 192.8 | 192.2 | 3.58 | 2.68 | 2.82 | | | | | | | | | | | | |
| 7 | 33-Lb. S.C. | 148 | 150 | -- | 193.9 | 193.9 | -- | 194.6 | 195.2 | -- | 0.93 | 0.95 | -- | 2.6 | 2.6 | -- | 100.0 | 100.0 | -- | 100.0 | 100.0 | -- | 100.0 | 100.0 |
| | | | 300 | -- | 193.5 | 193.9 | -- | 194.4 | 195.0 | -- | 1.03 | 1.76 | -- | 2.9 | 5.1 | -- | 100.0 | 85.0 | -- | 100.0 | 90.0 | -- | 100.0 | 97.5 |
| | | | 450 | -- | 192.5 | 192.1 | -- | 193.4 | 193.5 | -- | 1.47 | 2.98 | -- | 11.4 | 8.6 | -- | 92.5 | 57.5 | -- | 95.0 | 77.5 | -- | 97.5 | 85.0 |
| | | | 475 | -- | 192.6 | -- | -- | 194.5 | -- | -- | 2.76 | -- | -- | 8.6 | -- | -- | 67.5 | -- | -- | 87.5 | -- | -- | 90.0 | -- |
| | | | 500 | -- | -- | 192.7 | -- | -- | 193.7 | -- | -- | 3.52 | -- | -- | 7.6 | -- | -- | 47.5 | -- | -- | 65.0 | -- | -- | 72.5 |
| | | | Av. | -- | 193.1 | 193.2 | -- | 194.2 | 194.4 | -- | 1.55 | 2.30 | | | | | | | | | | | | |
| Composite average:[b] | | | | 192.8 | 192.0 | 191.7 | 195.7 | 194.2 | 194.0 | 3.47 | 2.88 | 2.71 | | | | | | | | | | | | |

[a] S.C. = semichemical; K = kraft; B = bogus.

[b] Excluding Medium 7 because results could not be obtained at 0 p.s.i. shower pressure.

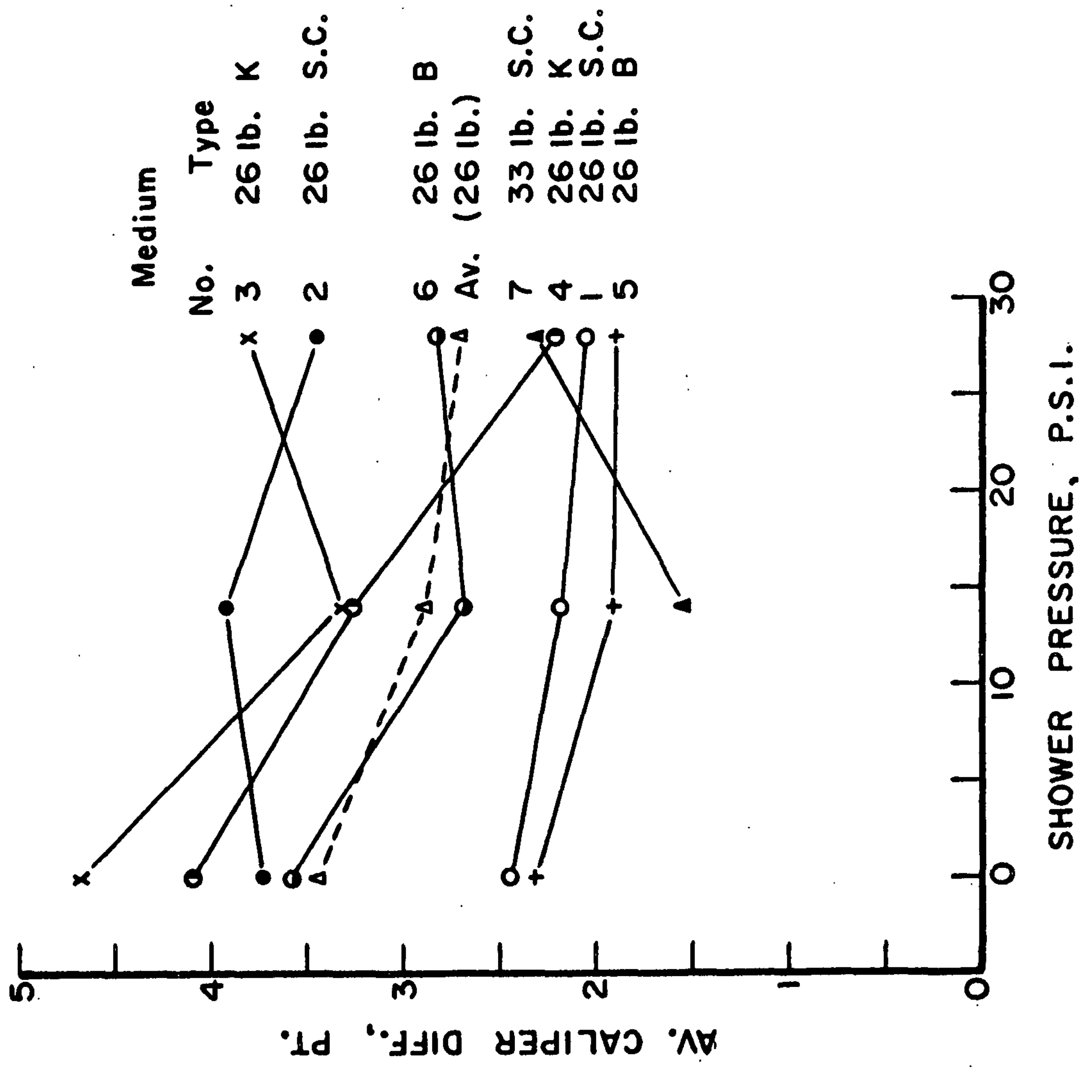


Figure 15. Effect of Steam Shower Pressure on Average Caliper Difference

To assess the statistical significance of the changes, the results at 300, 450, and 600 ft./min. for Mediums 2, 4, 5, and 6 were subjected to an analysis of variance. (Note: Results for remaining medium samples were not included in the analysis because data could not be obtained at each of the selected speed levels.) The data used in the analysis are summarized in Table XXVII and the variance analysis is shown in Table XXVIII. The analysis indicated that the effect of shower pressure on caliper differences approached significance at the 0.05 level (the effect was significant at the 0.10 level). Also, there was a significant interaction between shower pressure and medium sample — i.e., the effect of using the steam showers depended somewhat on the medium employed. As illustrated in Fig. 16, the deviations from parallelism between the relationships for the four mediums were greater than could be accounted by the experimental uncertainty — thus giving rise to the significant interaction. In fact, changes in shower pressure apparently had no significant effect on the caliper differences exhibited by Medium 5 (26-lb. bogus) as the differences shown would not be significant when compared against the 95% confidence limits shown in Fig. 16.

Taken as a whole it appears that the use of steam showers generally decreases caliper differences — and hence, high-low corrugations — though the magnitude of the improvement depends on the particular medium. Qualitatively, for the conditions of this study, it appears that the major reduction in caliper differences occurs in going from no shower to the "normal" shower pressure of 14 p.s.i.; further increases in shower pressure seem to have less effect.

In general, the use of showers tends to raise the temperature of the medium entering the nip. This should result in better molding of the flute. Also, the showers may alter the surface characteristics of the medium. For example, the coefficient of friction may be lowered, which would have the effect of increasing

TABLE XXVII

SUMMARY OF DATA USED IN ANALYSIS OF THE EFFECT OF STEAM SHOWER PRESSURE ON HIGH-LOW CORRUGATIONS

| Medium No. | Speed, ft./min. | Average Caliper Diff., pt. Shower Pressure, p.s.i. 0 | 14 | 28 | Composite |
|---|---|---|---|---|---|
| 2 | 300 | 4.03 | 3.02 | 3.20 | 3.49 |
| | 450 | 4.17 | 3.10 | 2.58 | |
| | 600 | 4.09[a] | 3.92 | 3.33 | |
| | Av. | 4.10 | 3.35 | 3.04 | |
| 4 | 300 | 2.54 | 2.53 | 1.35 | 2.50 |
| | 450 | 3.42 | 2.41 | 1.72 | |
| | 600 | 2.96 | 3.35 | 2.26 | |
| | Av. | 2.97 | 2.76 | 1.78 | |
| 5 | 300 | 1.70 | 1.74 | 1.62 | 1.84 |
| | 450 | 1.69 | 1.47 | 1.56 | |
| | 600 | 2.31 | 1.89 | 2.60 | |
| | Av. | 1.90 | 1.70 | 1.93 | |
| 6 | 300 | 3.53 | 2.39 | 2.52 | 2.74 |
| | 450 | 3.21 | 2.49 | 2.41 | |
| | 600 | 3.39 | 1.77 | 2.92 | |
| | Av. | 3.38 | 2.22 | 2.62 | |
| Average: | 300 | 2.95 | 2.42 | 2.17 | 2.51 |
| | 450 | 3.12 | 2.37 | 2.07 | 2.52 |
| | 600 | 3.19 | 2.73 | 2.78 | 2.90 |
| Composite average: | | 3.09 | 2.51 | 2.34 | |

[a]Sample taken at maximum runnability speed.

the runnability speed. These two factors – better molding and possible changes in surface characteristics – may be the mechanisms whereby steam showers affect high-low corrugations.

TABLE XXVIII

ANALYSIS OF THE EFFECT OF STEAM SHOWER PRESSURE ON AVERAGE CALIPER DIFFERENCE

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | $F$ |
|---|---|---|---|---|
| Between shower pressure ($SP$) | Fixed | 2 | 1.8464 | 4.08[a] |
| Between mediums ($M$) | Random | 3 | 4.1768 | 41.04[c] |
| Between speeds ($S$) | Fixed | 2 | 0.5853 | 4.11[a] |
| $SP \times M$ interaction | -- | 6 | 0.4524 | 4.44[b] |
| $M \times S$ interaction | -- | 6 | 0.1423 | 1.40 |
| $SP \times S$ interaction | -- | 4 | 0.1091 | 1.07 |
| Residual error | -- | 12 | 0.1018 | |

[a] Significant at the 0.10 level.
[b] Significant at the 0.05 level.
[c] Significant at the 0.01 level.

It may be noted in Table XXVIII that the differences between mediums with respect to average caliper difference were highly significant. The following composite differences were obtained:

| | Av. Caliper Difference, pt. |
|---|---|
| Medium 2 | 3.49 |
| Medium 4 | 2.50 |
| Medium 5 | 1.84 |
| Medium 6 | 2.74 |

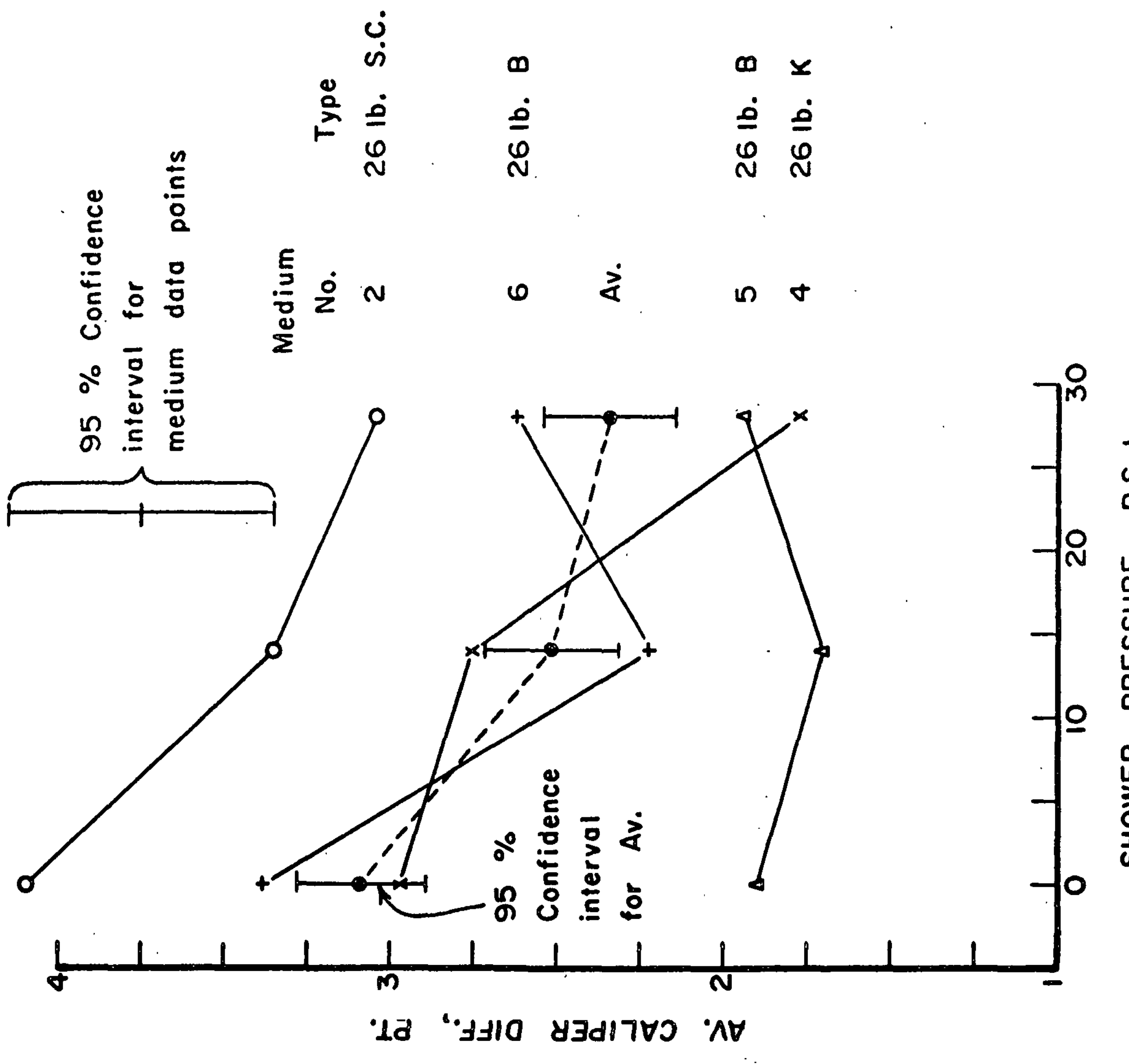


Figure 16. Effect of Steam Shower Pressure on Caliper Differences for Mediums Analyzed Statistically

Inasmuch as the 95% confidence interval for the medium composite averages is ± 0.23 pt., a number of the differences between mediums would be statistically significant confirming the analysis of variance results. Thus, it appears that significant differences in medium behavior with respect to their tendency to form high-low corrugations is obtained. What properties of the medium influence the high-low tendency is a pertinent question.

### Average Flute Height

An analysis similar to the above was carried out using the average caliper of the individual flutes. The data used are summarized in Table XXIX and the analysis of variance is shown in Table XXX. It may be noted that the effects of steam shower pressure on flute height were significant. As illustrated in Fig. 17, increasing shower pressure tended to slightly decrease flute height – particularly in going from no shower to 14 p.s.i. shower pressure. Above 14 p.s.i. shower pressure the flute height trends were not consistent. These conflicting trends gave rise to a significant interaction between shower pressure and medium – thus indicating that the effect of showers on flute height depends somewhat on the particular medium employed.

As in the web tension analysis, the differences in flute height between mediums were highly significant and a significant speed x medium interaction was obtained.

## EFFECT OF MEDIUM PREHEAT

### Average Caliper Difference

The amount of medium preheat was varied by changing the amount of wrap on the preheater. Three degrees of wrap were employed, namely, none, half, and full wrap. It should be kept in mind that the steam showers were employed in all

TABLE XXIX

SUMMARY OF DATA USED IN ANALYSIS OF THE EFFECT OF STEAM SHOWERS ON FLUTE HEIGHT

| Medium No. | Speed, ft./min. | Average Caliper, pt. Shower Pressure, p.s.i. 0 | 14 | 28 | Composite |
|---|---|---|---|---|---|
| 2 | 300 | 194.7 | 194.4 | 194.2 | 194.2 |
| | 450 | 194.3 | 194.1 | 193.5 | |
| | 600 | 194.3[a] | 194.4 | 193.5 | |
| | Av. | 194.4 | 194.3 | 193.7 | |
| 4 | 300 | 198.2 | 195.9 | 197.0 | 197.2 |
| | 450 | 198.2 | 196.3 | 196.6 | |
| | 600 | 198.8 | 196.4 | 197.2 | |
| | Av. | 198.4 | 196.5 | 196.9 | |
| 5 | 300 | 196.2 | 194.0 | 194.8 | 194.7 |
| | 450 | 195.7 | 193.5 | 193.7 | |
| | 600 | 196.3 | 193.7 | 194.0 | |
| | Av. | 196.1 | 193.7 | 194.5 | |
| 6 | 300 | 195.8 | 194.3 | 193.3 | 193.6 |
| | 450 | 194.5 | 192.6 | 192.6 | |
| | 600 | 195.2 | 192.2 | 191.7 | |
| | Av. | 195.2 | 193.0 | 192.5 | |
| Average: | 300 | 196.2 | 194.6 | 194.8 | 195.2 |
| | 450 | 195.7 | 194.1 | 194.1 | 194.6 |
| | 600 | 196.2 | 194.2 | 194.1 | 194.8 |
| Composite average: | | 196.0 | 194.3 | 194.3 | -- |

[a]Sample taken at maximum runnability speed.

cases; therefore, the temperatures of the mediums entering the corrugating nip were relatively high — even with no preheater wrap.

TABLE XXX

STATISTICAL ANALYSIS OF THE EFFECT OF
STEAM SHOWERS ON FLUTE HEIGHT

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | F |
|---|---|---|---|---|
| Between shower pressures (SP) | Fixed | 2 | 11.3500 | 10.48[a] |
| Between mediums (M) | Random | 3 | 22.6333 | 339.50[b] |
| Between speeds (S) | Fixed | 2 | 1.1000 | 2.36 |
| SP x M interaction | -- | 6 | 1.0833 | 16.25[b] |
| M x S interaction | -- | 6 | 0.4667 | 7.00[b] |
| SP x S interaction | -- | 4 | 0.1250 | 1.88 |
| Residual error | -- | 12 | 0.0667 | |

[a]Significant at the 0.05 level.
[b]Significant at the 0.01 level.

The results obtained are summarized in Table XXXI and the data selected for the statistical analysis are retabulated in Table XXXII. Referring to Table XXXII, or the analysis of variance results in Table XXXIII, it may be noted that, for the conditions of this study and analysis, changing the amount of medium preheat did not significantly affect the average caliper difference and, hence, the tendency to form high-low corrugations. While it might be argued that the higher medium temperatures achieved through use of the medium preheater should enhance the ability of the medium to mold itself to the flute contour, it appears that the higher temperatures had little effect on high-low corrugations for the data of this study.

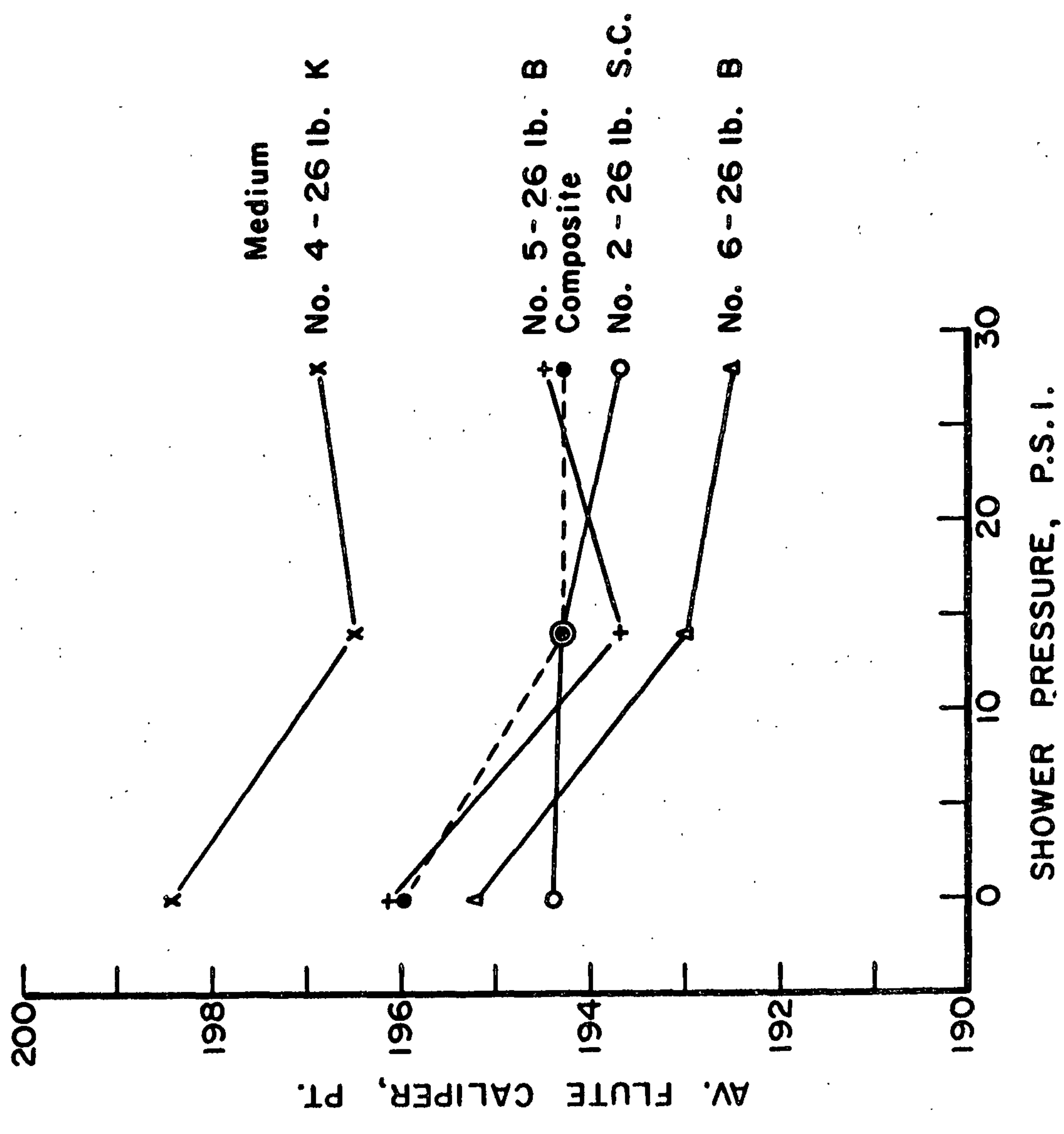


Figure 17. Effect of Steam Shower Pressure on Flute Height

TABLE XXXI

EFFECT OF AMOUNT OF MEDIUM PREHEAT ON HIGH-LOW CORRUGATIONS

| Medium Identification | | | Corr. | Single-Face Caliper, pt. | | | Individual Flute Caliper | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Av. Caliper, pt. | | | Av. Diff., pt. | | | Max. Diff., pt. | | | Cumulative Percentage of Differences in Flute Height, % | | | | | | | | |
| | | | | | | | | | | | | | | | | 0 - 3.0 pt. | | | 0 - 4.0 pt. | | | 0 - 5.0 pt. | | |
| | | Roll | Speed, | Preheater Wrap | | | Preheater Wrap | | | Preheater Wrap | | | Preheater Wrap | | | Preheater Wrap | | | Preheater Wrap | | | Preheater Wrap | | |
| No. | Type[a] | No. | ft./min. | None | Half | Full | None | Half | Full | None | Half | Full | None | Half | Full | None | Half | Full | None | Half | Full | None | Half | Full |
| 1 | 26-Lb. S.C. | 29 | 150 | 189.4 | -- | -- | 192.4 | -- | -- | 1.64 | -- | -- | 4.0 | -- | -- | 87.5 | -- | -- | 100.0 | -- | -- | 100.0 | -- | -- |
| | | | 300 | 189.5 | 190.2 | 191.4 | 192.5 | 193.7 | 194.2 | 1.98 | 3.02 | 1.37 | 5.0 | 6.5 | 5.7 | 72.5 | 52.5 | 85.0 | 97.5 | 75.0 | 90.0 | 100.0 | 85.0 | 97.5 |
| | | | 450 | 189.1 | 190.0 | 190.9 | 193.0 | 193.6 | 194.3 | 3.39 | 2.35 | 2.77 | 7.5 | 6.9 | 7.3 | 50.0 | 75.0 | 55.0 | 60.0 | 82.5 | 75.0 | 77.5 | 92.5 | 92.5 |
| | | | 600 | -- | 191.1 | 190.7 | -- | 194.1 | 194.1 | -- | 3.47 | 1.90 | -- | 11.8 | 6.2 | -- | 55.0 | 80.0 | -- | 62.5 | 90.0 | -- | 75.0 | 95.0 |
| | | | 625 | -- | 190.2 | 190.8 | -- | 194.2 | 194.1 | -- | 3.71 | 3.48 | -- | 11.6 | 9.7 | -- | 40.0 | 55.0 | -- | 62.5 | 72.5 | -- | 77.5 | 77.5 |
| | | | Av. | 189.3 | 190.4 | 191.0 | 192.6 | 193.9 | 194.2 | 2.34 | 3.14 | 2.38 | | | | | | | | | | | | |
| 2 | 26-Lb. S.C. | 60 | 150 | 190.5 | -- | -- | 193.2 | -- | -- | 1.72 | -- | -- | 5.2 | -- | -- | 82.5 | -- | -- | 92.5 | -- | -- | 97.5 | -- | -- |
| | | | 300 | 190.8 | 190.5 | 191.0 | 193.4 | 193.9 | 194.8 | 2.83 | 2.88 | 2.65 | 6.7 | 6.2 | 7.1 | 52.5 | 62.5 | 70.0 | 77.5 | 75.0 | 80.0 | 92.5 | 82.5 | 92.5 |
| | | | 450 | 189.2 | 190.1 | 190.7 | 192.4 | 193.3 | 194.4 | 4.74 | 4.34 | 2.92 | 9.3 | 8.8 | 7.0 | 37.5 | 35.0 | 55.0 | 42.5 | 40.0 | 77.5 | 47.5 | 55.0 | 85.0 |
| | | | 600 | -- | 190.7 | 189.7 | -- | 193.8 | 193.7 | -- | 3.96 | 2.59 | -- | 10.0 | 8.7 | -- | 42.5 | 67.5 | -- | 60.0 | 72.5 | -- | 65.0 | 90.0 |
| | | | 625 | -- | 191.0 | -- | -- | 194.2 | -- | -- | 4.25 | -- | -- | 11.3 | -- | -- | 45.0 | -- | -- | 57.5 | -- | -- | 62.5 | -- |
| | | | 775 | -- | -- | 190.1 | -- | -- | 194.3 | -- | -- | 3.98 | -- | -- | 10.5 | -- | -- | 50.0 | -- | -- | 57.5 | -- | -- | 70.0 |
| | | | Av. | 190.2 | 190.6 | 190.4 | 193.0 | 193.8 | 194.3 | 3.10 | 3.86 | 3.04 | | | | | | | | | | | | |
| 3 | 26-Lb. K | 47 | 150 | 188.8 | 190.1 | 190.8 | 192.3 | 193.6 | 193.8 | 2.29 | 3.12 | 3.31 | 7.0 | 8.6 | 8.5 | 70.0 | 45.0 | 52.5 | 85.0 | 75.0 | 72.5 | 92.5 | 85.0 | 77.5 |
| | | | 300 | 189.6 | 190.5 | 191.3 | 193.2 | 193.9 | 194.2 | 4.36 | 5.29 | 4.20 | 9.7 | 10.1 | 9.7 | 37.5 | 25.0 | 40.0 | 45.0 | 35.0 | 50.0 | 55.0 | 40.0 | 55.0 |
| | | | 325 | 189.2 | -- | 191.9 | 193.0 | -- | 194.9 | 5.15 | -- | 3.20 | 9.0 | -- | 8.0 | 20.0 | -- | 50.0 | 37.5 | -- | 60.0 | 45.0 | -- | 85.0 |
| | | | 350 | -- | -- | 188.5 | -- | -- | 194.0 | -- | -- | 3.84 | -- | -- | 8.0 | -- | -- | 40.0 | -- | -- | 50.0 | -- | -- | 67.5 |
| | | | 375 | -- | 189.5 | -- | -- | 194.2 | -- | -- | 4.18 | -- | -- | 9.3 | -- | -- | 40.0 | -- | -- | 57.5 | -- | -- | 62.5 | -- |
| | | | 425 | -- | 189.7 | -- | -- | 194.2 | -- | -- | 3.96 | -- | -- | 8.5 | -- | -- | 27.5 | -- | -- | 52.5 | -- | -- | 70.0 | -- |
| | | | Av. | 189.2 | 190.0 | 190.6 | 192.8 | 194.0 | 194.2 | 3.93 | 4.14 | 3.64 | | | | | | | | | | | | |
| 4 | 26-Lb. K | 145 | 300 | 193.5 | 194.9 | 194.1 | 195.4 | 196.4 | 195.6 | 1.79 | 3.32 | 2.77 | 4.9 | 6.7 | 6.7 | 80.0 | 45.0 | 60.0 | 92.5 | 70.0 | 75.0 | 100.0 | 85.0 | 90.0 |
| | | | 450 | 192.5 | 194.1 | 194.0 | 194.7 | 195.8 | 195.6 | 1.87 | 3.50 | 3.04 | 5.5 | 9.0 | 6.2 | 75.0 | 55.0 | 50.0 | 87.5 | 67.5 | 75.0 | 97.5 | 77.5 | 87.5 |
| | | | 600 | 193.7 | 194.2 | 194.2 | 195.3 | 196.2 | 195.8 | 2.93 | 2.57 | 2.54 | 9.7 | 9.3 | 5.9 | 62.5 | 67.5 | 62.5 | 75.0 | 82.5 | 80.0 | 80.0 | 87.5 | 87.5 |
| | | | 775 | 194.0 | -- | -- | 194.9 | -- | -- | 7.02 | -- | -- | 16.8 | -- | -- | 20.0 | -- | -- | 27.5 | -- | -- | 42.5 | -- | -- |
| | | | 1000 | -- | 194.1 | 193.8 | -- | 195.3 | 195.0 | -- | 5.74 | 4.84 | -- | 14.3 | 17.6 | -- | 32.5 | 35.0 | -- | 40.0 | 50.0 | -- | 47.5 | 57.5 |
| | | | Av. | 193.4 | 194.3 | 194.0 | 195.1 | 195.9 | 195.5 | 3.40 | 3.78 | 3.30 | | | | | | | | | | | | |
| 5 | 26-Lb. B | 85 | 300 | 190.3 | 191.3 | 191.3 | 193.1 | 194.2 | 194.1 | 1.39 | 1.86 | 2.57 | 3.7 | 9.0 | 5.6 | 85.0 | 87.5 | 62.5 | 100.0 | 92.5 | 85.0 | 100.0 | 95.0 | 95.0 |
| | | | 450 | 189.8 | 190.8 | 190.7 | 192.5 | 193.9 | 193.8 | 1.33 | 1.68 | 1.82 | 3.5 | 4.5 | 7.0 | 95.0 | 87.5 | 80.0 | 100.0 | 92.5 | 90.0 | 100.0 | 100.0 | 95.0 |
| | | | 600 | 189.7 | 191.0 | 191.3 | 192.6 | 193.7 | 194.2 | 1.79 | 2.40 | 2.74 | 5.2 | 5.6 | 6.7 | 77.5 | 72.5 | 57.5 | 92.5 | 80.0 | 80.0 | 97.5 | 95.0 | 90.0 |
| | | | 900 | 189.5 | -- | -- | 193.2 | -- | -- | 3.57 | -- | -- | 9.5 | -- | -- | 47.5 | -- | -- | 57.5 | -- | -- | 77.5 | -- | -- |
| | | | 1000 | -- | 190.7 | 190.8 | -- | 194.3 | 193.7 | -- | 2.95 | 3.54 | -- | 10.5 | 12.6 | -- | 65.0 | 55.0 | -- | 75.0 | 72.5 | -- | 85.0 | 77.5 |
| | | | Av. | 189.8 | 191.0 | 191.0 | 192.8 | 194.0 | 194.0 | 2.02 | 2.22 | 2.67 | | | | | | | | | | | | |
| 6 | 26-Lb. B | 89 | 300 | 189.5 | 189.8 | 190.8 | 192.0 | 192.8 | 193.4 | 2.30 | 2.31 | 2.34 | 5.3 | 5.7 | 5.4 | 70.0 | 72.5 | 65.0 | 90.0 | 80.0 | 82.5 | 97.5 | 92.5 | 97.5 |
| | | | 450 | 187.4 | 188.7 | 189.8 | 190.0 | 191.5 | 192.7 | 1.98 | 1.74 | 2.20 | 7.6 | 4.5 | 5.4 | 75.0 | 82.5 | 75.0 | 85.0 | 95.0 | 85.0 | 97.5 | 100.0 | 87.5 |
| | | | 500 | 186.9 | -- | -- | 189.5 | -- | -- | 3.02 | -- | -- | 6.2 | -- | -- | 42.5 | -- | -- | 77.5 | -- | -- | 92.5 | -- | -- |
| | | | 525 | 186.7 | -- | -- | 190.0 | -- | -- | 4.78 | -- | -- | 12.0 | -- | -- | 45.0 | -- | -- | 47.5 | -- | -- | 60.0 | -- | -- |
| | | | 600 | -- | 188.2 | 189.8 | -- | 191.2 | 192.6 | -- | 2.80 | 3.26 | -- | 7.7 | 8.0 | -- | 62.5 | 47.5 | -- | 82.5 | 62.5 | -- | 85.0 | 85.0 |
| | | | 750 | -- | 187.4 | -- | -- | 191.5 | -- | -- | 3.31 | -- | -- | 10.0 | -- | -- | 60.0 | -- | -- | 65.0 | -- | -- | 72.5 | -- |
| | | | 1000 | -- | -- | 188.6 | -- | -- | 191.1 | -- | -- | 4.25 | -- | -- | 14.0 | -- | -- | 35.0 | -- | -- | 60.0 | -- | -- | 77.5 |
| | | | Av. | 187.6 | 188.5 | 189.8 | 190.4 | 191.8 | 192.4 | 3.02 | 2.54 | 3.01 | | | | | | | | | | | | |
| 7 | 33-Lb. S.C. | 149 | 150 | 191.8 | 192.7 | 193.6 | 192.3 | 193.4 | 194.4 | 2.09 | 1.31 | 1.57 | 8.5 | 3.6 | 4.4 | 80.0 | 92.5 | 92.5 | 85.0 | 100.0 | 97.5 | 90.0 | 100.0 | 100.0 |
| | | | 300 | 192.0 | 192.1 | 193.5 | 192.5 | 192.9 | 194.5 | 2.82 | 1.99 | 2.49 | 10.0 | 5.8 | 9.5 | 65.0 | 75.0 | 75.0 | 75.0 | 80.0 | 80.0 | 90.0 | 90.0 | 90.0 |
| | | | 325 | 190.5 | -- | -- | 191.6 | -- | -- | 2.30 | -- | -- | 5.7 | -- | -- | 70.0 | -- | -- | 87.5 | -- | -- | 90.0 | -- | -- |
| | | | 450 | -- | 191.4 | 192.6 | -- | 192.6 | 193.8 | -- | 1.78 | 2.08 | -- | 5.2 | 6.4 | -- | 85.0 | 77.5 | -- | 92.5 | 87.5 | -- | 97.5 | 92.5 |
| | | | 475 | -- | -- | 192.4 | -- | -- | 193.5 | -- | -- | 3.46 | -- | -- | 8.6 | -- | -- | 50.0 | -- | -- | 67.5 | -- | -- | 75.0 |
| | | | Av. | 191.4 | 192.1 | 193.0 | 192.1 | 193.0 | 194.0 | 2.40 | 1.69 | 2.40 | | | | | | | | | | | | |
| Composite average: | | | | 190.1 | 191.0 | 191.4 | 192.7 | 193.8 | 194.1 | 2.89 | 3.05 | 2.92 | | | | | | | | | | | | |

[a] S.C. = semichemical; K = kraft; B = bogus.

TABLE XXXII

SUMMARY OF DATA USED IN STATISTICAL ANALYSIS OF THE EFFECT OF AMOUNT OF PREHEAT ON AVERAGE CALIPER DIFFERENCE

| Medium No. | Speed, ft./min. | Average Caliper Diff., pt. Preheater Wrap None | Half | Full | Composite |
|---|---|---|---|---|---|
| 1 | 300 | 1.98 | 3.02 | 1.37 | 2.48 |
| | 450 | 3.39 | 2.35 | 2.77 | |
| 2 | 300 | 2.83 | 2.88 | 2.65 | 3.39 |
| | 450 | 4.74 | 4.34 | 2.92 | |
| 4 | 300 | 1.79 | 3.32 | 2.77 | 2.72 |
| | 450 | 1.87 | 3.50 | 3.04 | |
| 5 | 300 | 1.39 | 1.86 | 2.57 | 1.78 |
| | 450 | 1.33 | 1.68 | 1.82 | |
| 6 | 300 | 2.30 | 2.31 | 2.34 | 2.14 |
| | 450 | 1.98 | 1.74 | 2.20 | |
| Average: | 300 | 2.06 | 2.68 | 2.34 | 2.36 |
| | 450 | 2.66 | 2.72 | 2.55 | 2.64 |
| Composite average: | | 2.36 | 2.70 | 2.44 | -- |

As in the case of web tension and steam showers, the differences in average caliper between mediums were highly significant. The composite averages are shown below:

| Medium No. | Type of Medium | Av. Caliper Difference, pt. |
|---|---|---|
| 1 | 26-Lb. S.C. | 2.48 |
| 2 | 26-Lb. S.C. | 3.39 |
| 4 | 26-Lb. kraft | 2.72 |
| 5 | 26-Lb. bogus | 1.78 |
| 6 | 26-Lb. bogus | 2.14 |

TABLE XXXIII

STATISTICAL ANALYSIS OF THE EFFECT OF AMOUNT
OF PREHEAT ON AVERAGE CALIPER DIFFERENCE

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | F |
|---|---|---|---|---|
| Between amount of preheat (PH) | Fixed | 2 | 0.3131 | 0.57 |
| Between mediums (M) | Random | 4 | 2.2445 | 9.30[a] |
| Between speeds (S) | Fixed | 1 | 0.6135 | 0.89 |
| PH x M interaction | -- | 8 | 0.5476 | 2.27 |
| M x S interaction | -- | 4 | 0.6863 | 2.84 |
| PH x S interaction | -- | 2 | 0.2068 | 0.86 |
| Residual error | -- | 8 | 0.2414 | |

[a]Significant at the 0.01 level.

## Average Flute Height

A similar analysis was carried out for the average caliper of the individual flutes. The data employed are summarized in Table XXXIV and the variance analysis is shown in Table XXXV. The variance analysis indicated that amount of preheat significantly affected flute height. In general, as shown in Fig. 18, flute height increased with increasing amounts of wrap in the preheater. Thus, the amount of medium preheat seems more influential in affecting flute height than flute height uniformity. In contrast, it may be interesting to note that varying steam shower pressure affected both flute height and uniformity.

TABLE XXXIV

SUMMARY OF DATA USED IN STATISTICAL ANALYSIS OF THE EFFECT OF AMOUNT OF PREHEAT ON FLUTE HEIGHT

| Medium No. | Speed, ft./min. | Average Caliper, pt. Preheater Wrap None | Half | Full | Composite |
|---|---|---|---|---|---|
| 1 | 300 | 192.5 | 193.7 | 194.2 | 193.6 |
| | 450 | 193.0 | 193.6 | 194.3 | |
| | Av. | 192.8 | 193.6 | 194.2 | |
| 2 | 300 | 193.4 | 193.9 | 194.8 | 193.7 |
| | 450 | 192.4 | 193.3 | 194.4 | |
| | Av. | 192.9 | 193.6 | 194.6 | |
| 4 | 300 | 195.4 | 196.4 | 195.6 | 195.6 |
| | 450 | 194.7 | 195.8 | 195.6 | |
| | Av. | 195.0 | 196.1 | 195.6 | |
| 5 | 300 | 193.1 | 194.2 | 194.1 | 193.6 |
| | 450 | 192.5 | 193.9 | 193.8 | |
| | Av. | 192.8 | 194.0 | 194.0 | |
| 6 | 300 | 192.0 | 192.8 | 193.4 | 192.1 |
| | 450 | 190.0 | 191.5 | 192.7 | |
| | Av. | 191.0 | 192.2 | 193.0 | |
| Average: | 300 | 193.3 | 194.2 | 194.4 | 194.0 |
| | 450 | 192.5 | 193.6 | 194.2 | 193.4 |
| Composite average: | | 192.9 | 193.9 | 194.3 | -- |

TABLE XXXV

STATISTICAL ANALYSIS OF EFFECT OF AMOUNT OF PREHEAT ON FLUTE HEIGHT

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | F |
|---|---|---|---|---|
| Between amount of preheat (PH) | Fixed | 2 | 5.150 | 20.60[a] |
| Between mediums (M) | Random | 4 | 9.375 | 125.00[a] |
| Between speeds (S) | Fixed | 1 | 2.100 | 5.25 |
| PH x M interaction | -- | 8 | 0.250 | 3.33 |
| M x S interaction | -- | 4 | 0.400 | 5.33[b] |
| PH x S interaction | -- | 2 | 0.150 | 2.00 |
| Residual error | -- | 8 | 0.075 | |

[a]Significant at the 0.01 level.

[b]Significant at the 0.05 level.

With regard to the differences in flute height between mediums, it may be noted that the differences, while small, were highly significant. This held true in the results previously discussed and appears to indicate that certain properties of the medium itself must influence flute height.

EFFECT OF ROLL PRESSURE

Average Caliper Differences

The effect of roll pressure on high-low corrugations was studied at three levels, namely, 187, 327, and 513 lb./in. of medium width. The "normal" operating pressure for the Institute's corrugator is 327 lb./in. The detailed results obtained are summarized in Table XXXVI. In general, the overall averages indicate that flute height increased with increased roll pressure. The caliper

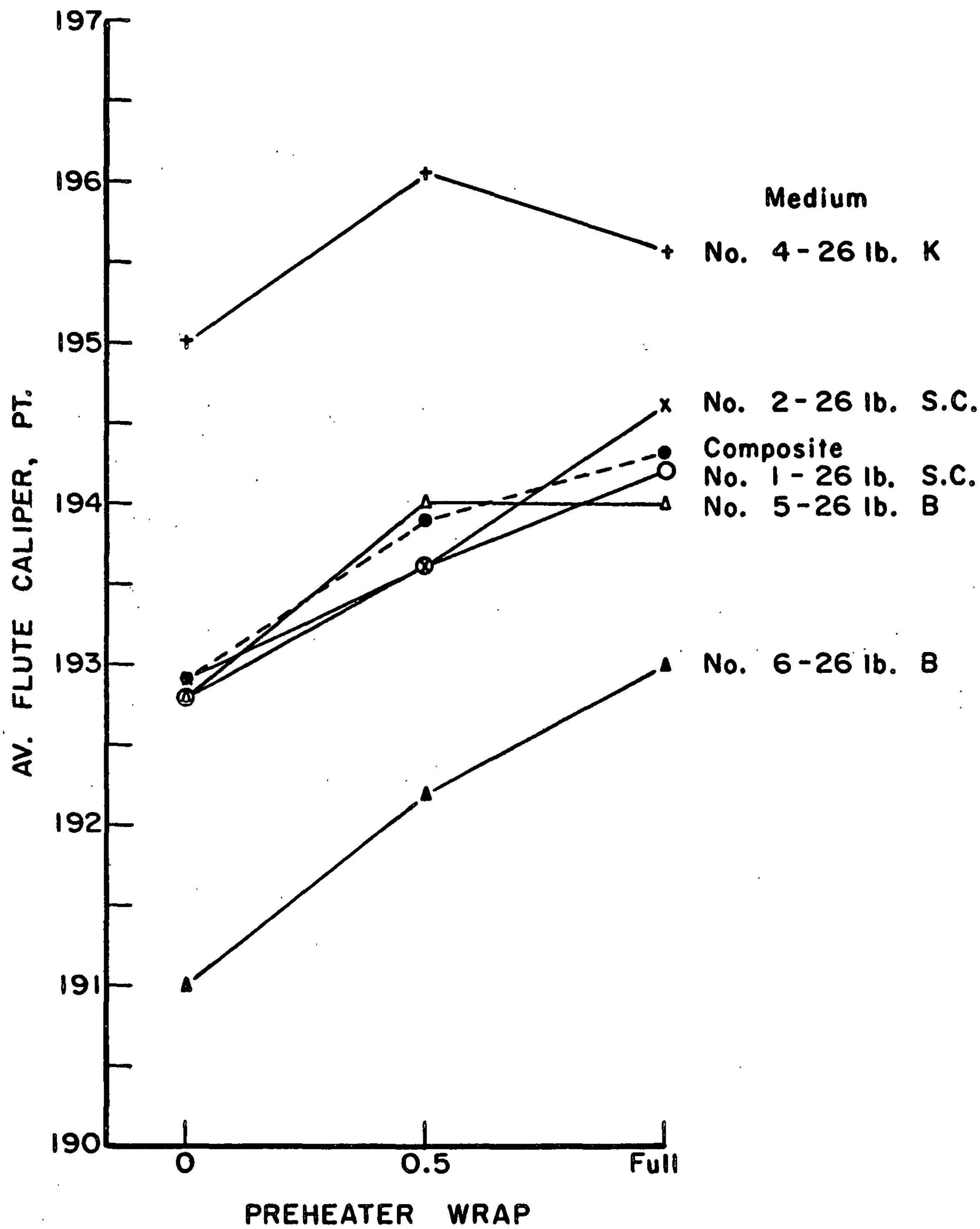


Figure 18. Effect of Amount of Preheat on Flute Height

TABLE XXXVI

EFFECT OF CORRUGATING ROLL PRESSURE ON HIGH-LOW CORRUGATIONS

| Medium Identification | | | Corr. Speed, ft./min. | Single-Face Caliper, pt. | | | Individual Flute Caliper: Av. Caliper, pt. | | | Av. Diff., pt. | | | Max. Diff., pt. | | | Cumulative Percentage of Differences in Flute Height, %: 0 - 3.0 pt. | | | 0 - 4.0 pt. | | | 0 - 5.0 pt. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Roll Pressure, lb./in. | | | Roll Pressure, lb./in. | | | Roll Pressure, lb./in. | | | Roll Pressure, lb./in. | | | Roll Pressure, lb./in. | | | Roll Pressure, lb./in. | | | Roll Pressure, lb./in. | | |
| No. | Type[a] | Roll No. | | 187 | 327 | 513 | 187 | 327 | 513 | 187 | 327 | 513 | 187 | 327 | 513 | 187 | 327 | 513 | 187 | 327 | 513 | 187 | 327 | 513 |
| 1 | 26-Lb. S.C. | 29 | 300 | 190.7 | 191.4 | 191.8 | 193.4 | 194.2 | 194.6 | 2.22 | 1.37 | 1.89 | 6.0 | 5.7 | 4.6 | 70.0 | 85.0 | 75.0 | 85.0 | 90.0 | 95.0 | 95.0 | 97.5 | 100.0 |
| | | | 450 | 189.4 | 190.9 | 191.5 | 193.1 | 194.3 | 194.9 | 3.38 | 2.77 | 2.21 | 10.3 | 7.3 | 7.2 | 55.0 | 55.0 | 80.0 | 67.5 | 75.0 | 85.0 | 75.0 | 92.5 | 92.5 |
| | | | 600 | 189.5 | 190.7 | 192.1 | 192.8 | 194.1 | 195.4 | 3.43 | 1.90 | 2.39 | 10.0 | 6.2 | 5.9 | 55.0 | 80.0 | 67.5 | 67.5 | 90.0 | 77.5 | 85.0 | 95.0 | 92.5 |
| | | | 625 | -- | 190.8 | -- | -- | 194.1 | -- | -- | 3.48 | -- | -- | 9.7 | -- | -- | 55.0 | -- | -- | 72.5 | -- | -- | 77.5 | -- |
| | | | 725 | -- | -- | 191.7 | -- | -- | 195.0 | -- | -- | 2.20 | -- | -- | 5.5 | -- | -- | 70.0 | -- | -- | 87.5 | -- | -- | 97.5 |
| | | | 750 | 189.5 | -- | -- | 192.6 | -- | -- | 4.86 | -- | -- | 13.8 | -- | -- | 30.0 | -- | -- | 40.0 | -- | -- | 60.0 | -- | -- |
| | | | Av. | 189.8 | 191.0 | 191.8 | 193.0 | 194.2 | 195.0 | 3.47 | 2.38 | 2.17 | | | | | | | | | | | | |
| 2 | 26-Lb. S.C. | 60 | 300 | 189.3 | 191.0 | 190.4 | 192.9 | 194.8 | 193.9 | 2.82 | 2.65 | 2.21 | 7.2 | 7.1 | 6.0 | 62.5 | 70.0 | 65.0 | 77.5 | 80.0 | 82.5 | 85.0 | 92.5 | 95.0 |
| | | | 450 | 188.6 | 190.7 | 191.8 | 192.8 | 194.4 | 194.9 | 4.75 | 2.92 | 2.40 | 10.4 | 7.0 | 8.0 | 25.0 | 55.0 | 70.0 | 42.5 | 77.5 | 82.5 | 60.0 | 85.0 | 90.0 |
| | | | 600 | 188.6 | 189.7 | 191.3 | 191.9 | 193.7 | 194.4 | 5.92 | 2.59 | 3.28 | 14.0 | 8.7 | 8.8 | 35.0 | 67.5 | 57.5 | 37.5 | 72.5 | 65.0 | 45.0 | 90.0 | 75.0 |
| | | | 650 | -- | -- | 191.6 | -- | -- | 194.6 | -- | -- | 3.87 | -- | -- | 9.1 | -- | -- | 37.5 | -- | -- | 62.5 | -- | -- | 75.0 |
| | | | 750 | 189.3 | -- | -- | 192.3 | -- | -- | 8.09 | -- | -- | 15.2 | -- | -- | 12.5 | -- | -- | 15.0 | -- | -- | 20.0 | -- | -- |
| | | | 775 | -- | 190.1 | -- | -- | 194.3 | -- | -- | 3.98 | -- | -- | 10.5 | -- | -- | 50.0 | -- | -- | 57.5 | -- | -- | 70.0 | -- |
| | | | Av. | 189.0 | 190.4 | 191.3 | 192.5 | 194.3 | 194.4 | 5.40 | 3.04 | 2.94 | | | | | | | | | | | | |
| 3 | 26-Lb. K | 47 | 150 | 191.2 | 190.8 | -- | 194.3 | 193.8 | -- | 2.30 | 3.31 | -- | 6.8 | 8.5 | -- | 70.0 | 52.5 | -- | 82.5 | 72.5 | -- | 92.5 | 77.5 | -- |
| | | | 300 | 189.7 | 191.3 | 192.2 | 193.1 | 194.2 | 194.8 | 3.89 | 4.20 | 4.03 | 8.0 | 9.7 | 7.7 | 47.5 | 40.0 | 40.0 | 55.0 | 50.0 | 45.0 | 65.0 | 55.0 | 57.5 |
| | | | 325 | -- | 191.9 | -- | -- | 194.9 | -- | -- | 3.20 | -- | -- | 8.0 | -- | -- | 50.0 | -- | -- | 60.0 | -- | -- | 85.0 | -- |
| | | | 350 | 190.0 | 188.5 | -- | 192.1 | 194.0 | -- | 5.02 | 3.84 | -- | 13.0 | 8.0 | -- | 42.5 | 40.0 | -- | 52.5 | 50.0 | -- | 52.5 | 67.5 | -- |
| | | | 375 | 189.3 | -- | -- | 192.9 | -- | -- | 2.95 | -- | -- | 8.5 | -- | -- | 65.0 | -- | -- | 70.0 | -- | -- | 77.5 | -- | -- |
| | | | 450 | -- | -- | 191.5 | -- | -- | 194.7 | -- | -- | 3.37 | -- | -- | 8.2 | -- | -- | 40.0 | -- | -- | 65.0 | -- | -- | 75.0 |
| | | | 600 | -- | -- | 191.7 | -- | -- | 195.5 | -- | -- | 4.12 | -- | -- | 9.0 | -- | -- | 37.5 | -- | -- | 55.0 | -- | -- | 65.0 |
| | | | 700 | -- | -- | 191.0 | -- | -- | 194.5 | -- | -- | 3.37 | -- | -- | 11.0 | -- | -- | 55.0 | -- | -- | 67.5 | -- | -- | 77.5 |
| | | | Av. | 190.0 | 190.6 | 191.6 | 193.1 | 194.2 | 194.9 | 3.54 | 3.64 | 3.72 | | | | | | | | | | | | |
| 4 | 26-Lb. K | 145 | 300 | 191.9 | 194.1 | 194.5 | 193.8 | 195.6 | 196.4 | 4.34 | 2.77 | 3.72 | 10.0 | 6.7 | 7.7 | 37.5 | 60.0 | 37.5 | 42.5 | 75.0 | 52.5 | 57.5 | 90.0 | 72.5 |
| | | | 450 | 191.1 | 194.0 | 193.7 | 192.9 | 195.6 | 196.2 | 6.55 | 3.04 | 3.10 | 15.5 | 6.2 | 6.4 | 22.5 | 50.0 | 55.0 | 40.0 | 75.0 | 65.0 | 50.0 | 87.5 | 82.5 |
| | | | 600 | 190.7 | 194.2 | 195.5 | 192.9 | 195.8 | 197.0 | 5.74 | 2.54 | 4.25 | 14.9 | 5.9 | 9.0 | 25.0 | 62.5 | 27.5 | 35.0 | 80.0 | 47.5 | 47.5 | 87.5 | 67.5 |
| | | | 725 | 191.5 | -- | -- | 193.8 | -- | -- | 5.81 | -- | -- | 16.4 | -- | -- | 30.0 | -- | -- | 45.0 | -- | -- | 57.5 | -- | -- |
| | | | 900 | -- | -- | 194.9 | -- | -- | 197.3 | -- | -- | 3.46 | -- | -- | 9.0 | -- | -- | 45.0 | -- | -- | 65.0 | -- | -- | 77.5 |
| | | | 1000 | -- | 193.8 | -- | -- | 195.0 | -- | -- | 4.84 | -- | -- | 17.6 | -- | -- | 35.0 | -- | -- | 50.0 | -- | -- | 57.5 | -- |
| | | | Av. | 191.3 | 194.0 | 194.6 | 193.4 | 195.5 | 196.7 | 5.61 | 3.30 | 3.63 | | | | | | | | | | | | |
| 5 | 26-Lb. B | 85 | 300 | 190.3 | 191.3 | 191.8 | 193.0 | 194.1 | 194.9 | 2.67 | 2.57 | 1.67 | 13.0 | 5.6 | 3.7 | 72.5 | 62.5 | 90.0 | 80.0 | 85.0 | 100.0 | 85.0 | 95.0 | 100.0 |
| | | | 450 | 190.1 | 190.7 | 191.9 | 193.3 | 193.8 | 195.2 | 1.72 | 1.82 | 1.46 | 5.3 | 7.0 | 4.0 | 87.5 | 80.0 | 92.5 | 90.0 | 90.0 | 100.0 | 97.5 | 95.0 | 100.0 |
| | | | 600 | 190.0 | 191.3 | 192.5 | 193.0 | 194.2 | 195.4 | 2.63 | 2.74 | 1.62 | 8.7 | 6.7 | 4.5 | 65.0 | 57.5 | 90.0 | 77.5 | 80.0 | 95.0 | 80.0 | 90.0 | 100.0 |
| | | | 1000 | 191.2 | 190.8 | 191.7 | 193.6 | 193.7 | 194.4 | 2.87 | 3.54 | 2.69 | 8.0 | 12.6 | 8.2 | 62.5 | 55.0 | 62.5 | 72.5 | 72.5 | 77.5 | 75.0 | 77.5 | 92.5 |
| | | | Av. | 190.4 | 191.0 | 192.0 | 193.2 | 194.0 | 195.0 | 2.47 | 2.67 | 1.86 | | | | | | | | | | | | |
| 6 | 26-Lb. B | 89 | 300 | 188.6 | 190.8 | 191.1 | 191.5 | 193.4 | 194.0 | 1.68 | 2.34 | 2.50 | 4.5 | 5.4 | 7.1 | 87.5 | 65.0 | 72.5 | 97.5 | 82.5 | 85.0 | 100.0 | 97.5 | 97.5 |
| | | | 450 | 187.2 | 189.8 | 190.6 | 190.3 | 192.7 | 193.8 | 2.15 | 2.20 | 2.90 | 5.5 | 5.4 | 6.4 | 80.0 | 75.0 | 62.5 | 90.0 | 85.0 | 72.5 | 97.5 | 87.5 | 90.0 |
| | | | 600 | 188.3 | 189.8 | 190.8 | 191.2 | 192.6 | 193.8 | 2.74 | 3.26 | 2.35 | 7.5 | 8.0 | 5.5 | 67.5 | 47.5 | 65.0 | 80.0 | 62.5 | 87.5 | 85.0 | 85.0 | 97.5 |
| | | | 1000 | 188.2 | 188.6 | 189.2 | 191.3 | 191.1 | 192.0 | 4.05 | 4.25 | 5.42 | 14.1 | 14.0 | 14.0 | 52.5 | 35.0 | 30.0 | 60.0 | 60.0 | 37.5 | 70.0 | 77.5 | 52.5 |
| | | | Av. | 188.1 | 189.8 | 190.4 | 191.1 | 192.4 | 193.4 | 2.66 | 3.01 | 3.29 | | | | | | | | | | | | |
| 7 | 33-Lb. S.C. | 149 | 150 | 191.8 | 193.6 | 193.6 | 193.0 | 194.4 | 194.5 | 3.16 | 1.57 | 1.53 | 10.9 | 4.4 | 3.6 | 55.0 | 92.5 | 97.5 | 70.0 | 97.5 | 100.0 | 85.0 | 100.0 | 100.0 |
| | | | 300 | 191.7 | 193.5 | 192.9 | 192.4 | 194.5 | 194.2 | 4.28 | 2.49 | 1.94 | 11.1 | 9.5 | 5.0 | 42.5 | 75.0 | 80.0 | 55.0 | 80.0 | 87.5 | 62.5 | 90.0 | 100.0 |
| | | | 450 | 189.0 | 192.6 | 192.4 | 190.9 | 193.8 | 193.7 | 3.66 | 2.08 | 2.44 | 13.0 | 6.4 | 7.0 | 67.5 | 77.5 | 67.5 | 75.0 | 87.5 | 82.5 | 75.0 | 92.5 | 95.0 |
| | | | 475 | -- | 192.4 | -- | -- | 193.5 | -- | -- | 3.46 | -- | -- | 8.6 | -- | -- | 50.0 | -- | -- | 67.5 | -- | -- | 75.0 | -- |
| | | | 500 | -- | -- | 191.9 | -- | -- | 193.7 | -- | -- | 3.33 | -- | -- | 7.8 | -- | -- | 52.5 | -- | -- | 62.5 | -- | -- | 70.0 |
| | | | Av. | 190.8 | 193.0 | 192.7 | 192.1 | 194.0 | 194.0 | 3.70 | 2.40 | 2.31 | | | | | | | | | | | | |
| | Composite average: | | | 189.9 | 191.4 | 192.1 | 192.6 | 194.1 | 194.8 | 3.84 | 2.92 | 2.85 | | | | | | | | | | | | |

[a]S.C. = semichemical; K = kraft; B = bogus.

differences were highest at the lowest roll pressure and were approximately equal at the two higher pressures.

An analysis of variance was carried out to determine if the changes in average caliper difference with changes in roll pressure were statistically significant. The data employed in the analysis are summarized in Table XXXVII and the variance table is shown in Table XXXVIII. The analysis indicated that pressure, by itself, was not a highly significant factor (significant at the 0.10 level); however, a highly significant interaction between pressure and medium sample was obtained. As illustrated in Fig. 19, the different mediums exhibited diverse trends with increasing roll pressure giving rise to the significant interaction. It appears that at low roll pressures certain mediums tend to exhibit higher caliper differences which might result in high-low corrugations at the double-backer. Other mediums at low roll pressures exhibit caliper differences which may be no greater than are encountered at high roll pressures. Increasing roll pressure above the "normal" pressure of 327 lb./in. had little effect for four of the mediums and gave rise to opposing trends for the other two mediums.

In general, it appears that operating at low roll pressures will, with some mediums, result in a greater tendency to high-low corrugations.

As mentioned in previous sections, there were significant differences between mediums with regard to caliper differences and, hence, high-low corrugations.

Average Flute Height

An analysis similar to the above was carried out for flute height (average caliper of individual flutes). The data are summarized in Table XXXIX and the variance analysis is shown in Table XL. Referring to the table or Fig. 20, it may be noted

TABLE XXXVII

SUMMARY OF DATA USED IN STATISTICAL ANALYSIS OF THE EFFECT OF ROLL PRESSURE ON AVERAGE CALIPER DIFFERENCE

| Medium No. | Speed, ft./min. | Average Caliper Diff., pt. Roll Pressure, lb./in. 187 | 327 | 513 | Composite |
|---|---|---|---|---|---|
| 1 | 300 | 2.22 | 1.37 | 1.89 | 2.40 |
| | 450 | 3.38 | 2.77 | 2.21 | |
| | 600 | 3.43 | 1.90 | 2.39 | |
| | Av. | 3.01 | 2.01 | 2.16 | |
| 2 | 300 | 2.82 | 2.65 | 2.21 | 3.28 |
| | 450 | 4.75 | 2.92 | 2.40 | |
| | 600 | 5.92 | 2.59 | 3.28 | |
| | Av. | 4.50 | 2.72 | 2.63 | |
| 4 | 300 | 4.34 | 2.77 | 3.72 | 4.01 |
| | 450 | 6.55 | 3.04 | 3.10 | |
| | 600 | 5.74 | 2.54 | 4.25 | |
| | Av. | 5.54 | 2.78 | 3.69 | |
| 5 | 300 | 2.67 | 2.57 | 1.67 | 2.10 |
| | 450 | 1.72 | 1.82 | 1.46 | |
| | 600 | 2.63 | 2.74 | 1.62 | |
| | Av. | 2.34 | 2.71 | 1.58 | |
| 6 | 300 | 1.68 | 2.34 | 2.50 | 2.46 |
| | 450 | 2.15 | 2.20 | 2.90 | |
| | 600 | 2.74 | 3.26 | 2.35 | |
| | Av. | 2.19 | 2.60 | 2.58 | |
| Average: | 300 | 2.75 | 2.34 | 2.40 | 2.49 |
| | 450 | 3.71 | 2.55 | 2.41 | 2.89 |
| | 600 | 4.09 | 2.61 | 2.78 | 3.16 |
| Composite average: | | 3.52 | 2.50 | 2.53 | -- |

that increased roll pressures generally produced significantly higher flute heights. In most instances the greatest change in flute height occurred in going from 187 to 327 lb./in. roll pressure and a somewhat lesser change occurred as roll pressure was increased from 327 to 513 lb./in. Thus, reduced roll pressures resulted in lower flute heights and, as noted previously, in higher caliper differences for some mediums.

TABLE XXXVIII

ANALYSIS OF THE EFFECT OF ROLL PRESSURE ON THE AVERAGE CALIPER DIFFERENCE

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | *F* |
|---|---|---|---|---|
| Between roll pressures (*P*) | Fixed | 2 | 5.0204 | 3.42[a] |
| Between mediums (*M*) | Random | 4 | 5.5012 | 18.22[b] |
| Between speeds (*S*) | Fixed | 2 | 1.6743 | 4.27[a] |
| *P* x *M* interaction | -- | 8 | 1.4677 | 4.86[b] |
| *M* x *S* interaction | -- | 8 | 0.3921 | 1.30 |
| *P* x *S* interaction | -- | 4 | 0.5304 | 1.76 |
| Residual error | -- | 16 | 0.3019 | |

[a]Significant at the 0.10 level.
[b]Significant at the 0.01 level.

EFFECT OF ROLL PARALLELISM

As in the case of runnability, the effects of roll parallelism on high-low corrugations were studied at three conditions. For the first condition, the bearings were adjusted to give even pressures across the roll width as evidenced

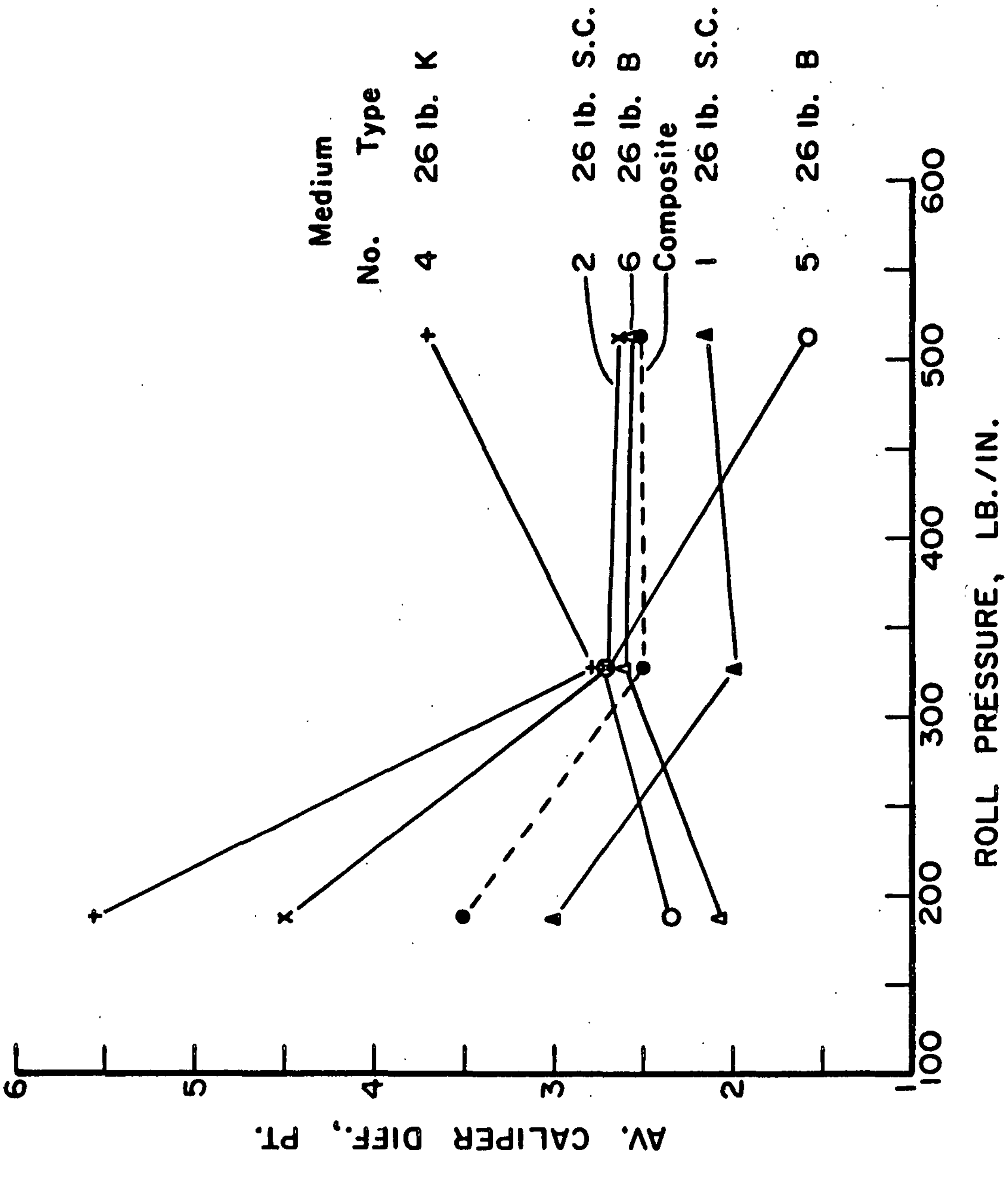


Figure 19. Effect of Roll Pressure on the Average Caliper Difference

TABLE XXXIX

SUMMARY OF DATA USED IN STATISTICAL ANALYSIS OF THE EFFECT OF ROLL PRESSURE ON FLUTE HEIGHT

| Medium No. | Speed, ft./min. | Average Caliper, pt. Roll Pressure, lb./in. 187 | 327 | 513 | Composite |
|---|---|---|---|---|---|
| 1 | 300 | 193.4 | 194.2 | 194.6 | 194.1 |
| | 450 | 193.1 | 194.3 | 194.9 | |
| | 600 | 192.8 | 194.1 | 195.4 | |
| | Av. | 193.1 | 194.2 | 195.0 | |
| 2 | 300 | 192.9 | 194.8 | 193.9 | 193.7 |
| | 450 | 192.8 | 194.4 | 194.9 | |
| | 600 | 191.9 | 193.7 | 194.4 | |
| | Av. | 192.5 | 194.3 | 194.4 | |
| 4 | 300 | 193.8 | 195.6 | 196.4 | 195.1 |
| | 450 | 192.9 | 195.6 | 196.2 | |
| | 600 | 192.9 | 195.8 | 197.0 | |
| | Av. | 193.2 | 195.7 | 196.5 | |
| 5 | 300 | 193.0 | 194.1 | 194.9 | 194.1 |
| | 450 | 193.3 | 193.8 | 195.2 | |
| | 600 | 193.0 | 194.2 | 195.4 | |
| | Av. | 193.1 | 194.0 | 195.2 | |
| 6 | 300 | 191.5 | 193.4 | 194.0 | 192.6 |
| | 450 | 190.3 | 192.7 | 193.8 | |
| | 600 | 191.2 | 192.6 | 193.8 | |
| | Av. | 191.0 | 192.9 | 193.9 | |
| Average: | 300 | 192.9 | 194.4 | 194.8 | 194.0 |
| | 450 | 192.5 | 194.2 | 195.0 | 193.9 |
| | 600 | 192.4 | 194.1 | 195.2 | 193.9 |
| Composite average: | | 192.6 | 194.2 | 195.0 | -- |

by pressure patterns. For the other two conditions the main corrugating roll bearing was rotated, in one case, 3/32 inch and, in the other case, 3/16 inch. These rotations resulted in quite noticeable differences in side-wall pressure across the roll width in the pressure patterns. The detailed results obtained are summarized in Table XLI and the results selected for statistical analysis are shown in Table XLII.

TABLE XL

ANALYSIS OF THE EFFECT OF ROLL PRESSURE ON FLUTE HEIGHT

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | $\underline{F}$ |
|---|---|---|---|---|
| Between roll pressures ($\underline{P}$) | Fixed | 2 | 22.5389 | 45.58[b] |
| Between mediums ($\underline{M}$) | Random | 4 | 7.5041 | 90.20[b] |
| Between speeds ($\underline{S}$) | Fixed | 2 | 0.1176 | 0.58 |
| $\underline{P}$ x $\underline{M}$ interaction | -- | 8 | 0.4944 | 5.94[b] |
| $\underline{M}$ x $\underline{S}$ interaction | -- | 8 | 0.2031 | 2.44 |
| $\underline{P}$ x $\underline{S}$ interaction | -- | 4 | 0.3589 | 4.31[a] |
| Residual error | -- | 16 | 0.0832 | |

[a]Significant at the 0.05 level.
[b]Significant at the 0.01 level.

## Average Caliper Difference

In Table XLII it may be noted that, on the average, the following caliper differences were obtained:

| | Av. Caliper Diff., pt. |
|---|---|
| "Normal" roll parallelism adjustment | 2.66 |
| Bearing cam rotated, 3/32 inch | 3.55 |
| Bearing cam rotated, 3/16 inch | 3.04 |

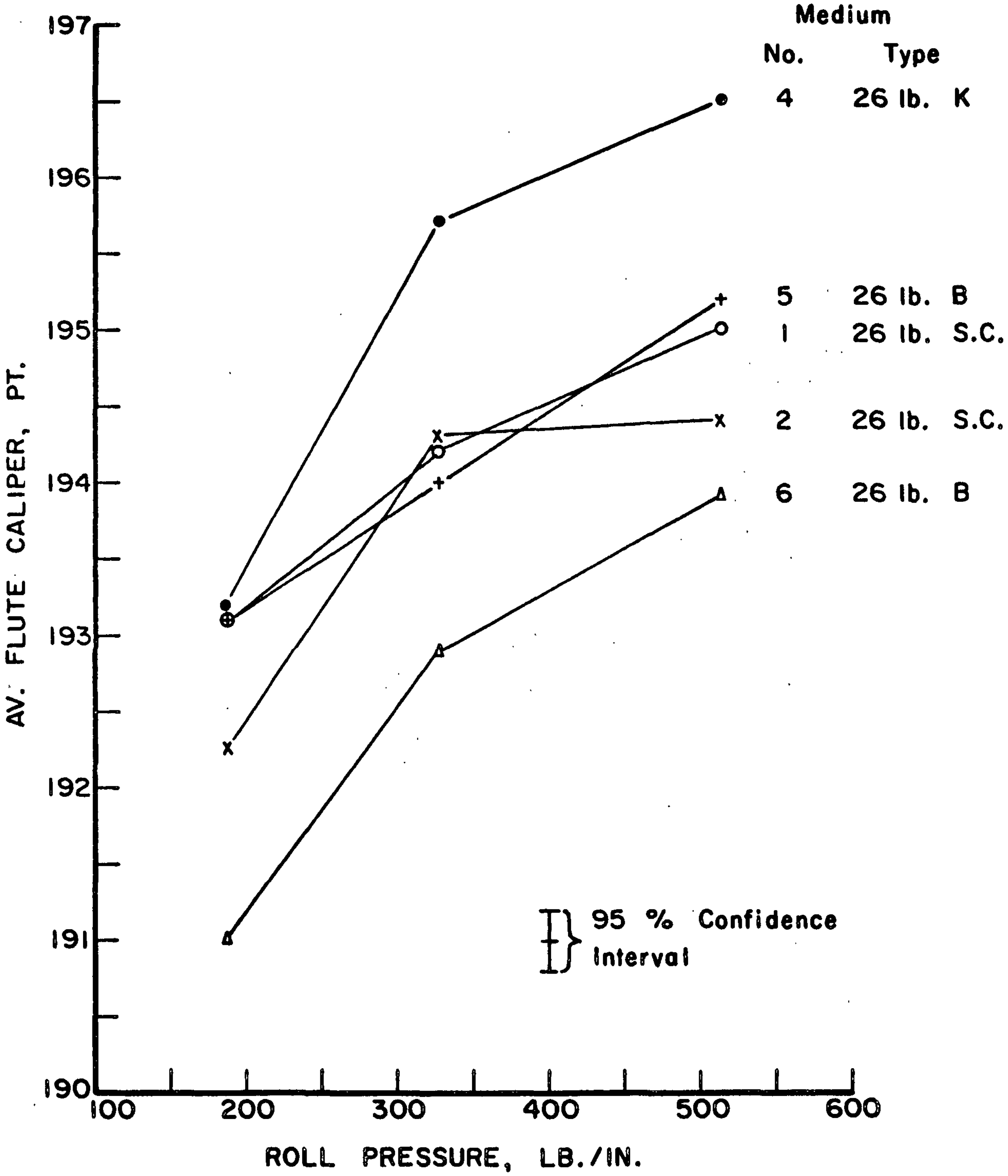


Figure 20. Effect of Roll Pressure on Flute Height

TABLE XLI

EFFECT OF CORRUGATING ROLL PARALLELISM ON HIGH-LOW CORRUGATIONS

| Medium Identification | | | Corr. Speed, ft./min. | Single-Face Caliper, pt. | | | Individual Flute Caliper | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Av. Caliper, pt. | | | Av. Diff., pt. | | | Max. Diff., pt. | | | Cumulative Percentage of Differences in Flute Height, % | | | | | | | | |
| | | | | | | | | | | | | | | | | 0 - 3.0 pt. | | | 0 - 4.0 pt. | | | 0 - 5.0 pt. | | |
| | | | | Bearing Adjustment, in.[a] | | | Bearing Adjustment, in.[a] | | | Bearing Adjustment, in.[a] | | | Bearing Adjustment, in.[a] | | | Bearing Adjustment, in.[a] | | | Bearing Adjustment, in.[a] | | | Bearing Adjustment, in.[a] | | |
| No. | Type[b] | Roll No. | | 3/16 | 3/32 | None | 3/16 | 3/32 | None | 3/16 | 3/32 | None | 3/16 | 3/32 | None | 3/16 | 3/32 | None | 3/16 | 3/32 | None | 3/16 | 3/32 | None |
| 1 | 26-Lb. S.C. | 30 | 150 | -- | 191.3 | -- | -- | 193.9 | -- | -- | 1.80 | -- | -- | 4.2 | -- | -- | 80.0 | -- | -- | 95.0 | -- | -- | 100.0 | -- |
| | | | 300 | 191.4 | 191.3 | 192.2 | 193.8 | 193.3 | 194.2 | 2.17 | 2.66 | 1.98 | 5.3 | 7.1 | 6.1 | 72.5 | 62.5 | 77.5 | 92.5 | 82.5 | 92.5 | 97.5 | 95.0 | 95.0 |
| | | | 450 | 191.4 | 190.5 | 192.0 | 193.8 | 193.1 | 194.1 | 2.96 | 3.29 | 2.71 | 6.6 | 7.3 | 7.1 | 52.5 | 60.0 | 67.5 | 75.0 | 62.5 | 77.5 | 87.5 | 75.0 | 80.0 |
| | | | 600 | 191.5 | 190.8 | 191.9 | 194.1 | 194.0 | 194.1 | 2.86 | 3.96 | 3.57 | 5.8 | 9.2 | 8.4 | 57.5 | 42.5 | 52.5 | 72.5 | 50.0 | 62.5 | 85.0 | 67.5 | 75.0 |
| | | | 700 | -- | -- | 192.0 | -- | -- | 194.2 | -- | -- | 3.40 | -- | -- | 10.0 | -- | -- | 57.5 | -- | -- | 65.0 | -- | -- | 75.0 |
| | | | 725 | 191.4 | -- | -- | 194.0 | -- | -- | 3.84 | -- | -- | 10.0 | -- | -- | 42.5 | -- | -- | 55.0 | -- | -- | 67.5 | -- | -- |
| | | | Av. | 191.4 | 191.0 | 192.0 | 193.9 | 193.6 | 194.2 | 2.96 | 2.93 | 2.91 | | | | | | | | | | | | |
| 4 | 26-Lb. K | 147 | 300 | 192.6 | 193.6 | 193.3 | 194.5 | 195.7 | 194.8 | 2.81 | 3.33 | 1.80 | 7.8 | 7.2 | 4.8 | 65.0 | 50.0 | 77.5 | 77.5 | 62.5 | 87.5 | 90.0 | 72.5 | 100.0 |
| | | | 450 | 193.3 | 192.7 | 192.7 | 194.6 | 195.0 | 194.6 | 3.81 | 3.98 | 2.10 | 8.0 | 8.4 | 6.3 | 47.5 | 35.0 | 82.5 | 55.0 | 52.5 | 85.0 | 72.5 | 67.5 | 97.5 |
| | | | 600 | 192.6 | 192.4 | 193.6 | 194.7 | 195.2 | 195.1 | 3.42 | 3.08 | 3.16 | 10.3 | 7.9 | 8.0 | 52.5 | 57.5 | 60.0 | 62.5 | 65.0 | 67.5 | 72.5 | 72.5 | 77.5 |
| | | | 900 | 190.3 | 191.9 | -- | 192.4 | 193.4 | -- | 5.98 | 7.33 | -- | 19.5 | 14.5 | -- | 25.0 | 22.5 | -- | 47.5 | 25.0 | -- | 62.5 | 32.5 | -- |
| | | | 1000 | -- | -- | 191.2 | -- | -- | 193.2 | -- | -- | 6.60 | -- | -- | 18.7 | -- | -- | 22.5 | -- | -- | 30.0 | -- | -- | 37.5 |
| | | | Av. | 192.2 | 192.6 | 192.7 | 194.0 | 194.8 | 194.4 | 4.00 | 4.43 | 3.42 | | | | | | | | | | | | |
| 6 | 26-Lb. B | 90 | 300 | 191.6 | 191.7 | 192.3 | 193.5 | 193.5 | 193.9 | 3.20 | 3.26 | 3.03 | 7.3 | 7.3 | 8.4 | 52.5 | 52.5 | 57.5 | 62.5 | 67.5 | 65.0 | 77.5 | 77.5 | 77.5 |
| | | | 450 | 190.6 | 190.0 | 190.2 | 192.8 | 192.1 | 192.2 | 2.64 | 3.20 | 2.59 | 8.0 | 8.8 | 5.4 | 70.0 | 47.5 | 52.5 | 80.0 | 60.0 | 80.0 | 87.5 | 80.0 | 90.0 |
| | | | 600 | 191.0 | 190.3 | 189.9 | 193.0 | 191.9 | 191.9 | 3.43 | 4.51 | 3.01 | 11.3 | 9.6 | 8.6 | 62.5 | 32.5 | 60.0 | 75.0 | 42.5 | 75.0 | 82.5 | 50.0 | 80.0 |
| | | | 900 | 189.0 | 189.1 | 189.0 | 191.3 | 191.2 | 191.3 | 3.35 | 3.59 | 3.89 | 10.8 | 11.5 | 11.5 | 57.5 | 57.5 | 50.0 | 70.0 | 72.5 | 65.0 | 75.0 | 77.5 | 75.0 |
| | | | Av. | 190.6 | 190.3 | 190.4 | 192.6 | 192.2 | 192.3 | 3.16 | 3.64 | 3.13 | | | | | | | | | | | | |
| Composite average: | | | | 191.4 | 191.3 | 191.7 | 193.5 | 193.5 | 193.6 | 3.37 | 3.67 | 3.15 | | | | | | | | | | | | |

[a]Bearing rotated 3/32 and 3/16 inch, respectively, from normal position.

[b]S.C. = semichemical; K = kraft; B = bogus.

TABLE XLII

SUMMARY OF DATA USED IN STATISTICAL ANALYSES OF THE EFFECT OF ROLL PARALLELISM ON HIGH-LOW CORRUGATIONS

| Medium No. | Speed, ft./min. | Average Caliper, pt. Bearing Adjustment, in.[a] 3/16 | 3/32 | None | Composite | Average Caliper Diff., pt. Bearing Adjustment, in.[a] 3/16 | 3/32 | None | Composite |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 300 | 193.8 | 193.3 | 194.2 | | 2.17 | 2.66 | 1.98 | |
| | 450 | 193.8 | 193.1 | 194.1 | 193.8 | 2.96 | 3.29 | 2.71 | 2.91 |
| | 600 | 194.1 | 194.0 | 194.1 | | 2.86 | 3.96 | 3.57 | |
| 4 | 300 | 194.5 | 195.7 | 194.8 | | 2.81 | 3.33 | 1.80 | |
| | 450 | 194.6 | 195.0 | 194.6 | 194.9 | 3.81 | 3.98 | 2.10 | 3.05 |
| | 600 | 194.7 | 195.2 | 195.1 | | 3.42 | 3.08 | 3.16 | |
| 6 | 300 | 193.5 | 193.5 | 193.9 | | 3.20 | 3.26 | 3.03 | |
| | 450 | 192.8 | 192.1 | 192.2 | 192.8 | 2.64 | 3.20 | 2.59 | 3.21 |
| | 600 | 193.0 | 191.9 | 191.9 | | 3.43 | 4.51 | 3.01 | |
| Average: | 300 | 193.9 | 194.2 | 194.3 | | 2.73 | 3.30 | 2.27 | |
| | 450 | 193.7 | 193.4 | 193.8 | 193.8 | 3.14 | 3.49 | 2.47 | 3.08 |
| | 600 | 193.9 | 193.7 | 193.7 | | 3.24 | 3.85 | 3.24 | |
| Composite average: | | 193.8 | 193.8 | 193.9 | | 3.04 | 3.55 | 2.66 | |

[a] Bearing rotated 3/32 and 3/16 inch from its normal position.

As may be noted, somewhat higher caliper differences were obtained with the rolls out of parallel alignment. The analysis of variance in Table XLIII indicates that the differences due to the bearing adjustments failed to reach significance at the 0.05 level. However, they were significant at the 0.10 level. Consequently, it appears that deviations from roll parallelism may tend to increase the tendency to high-low corrugations; however, the magnitudes of the changes were not great enough to be highly significant for the conditions and materials of this study.

TABLE XLIII

ANALYSIS OF THE EFFECT OF ROLL PARALLELISM
ON THE AVERAGE CALIPER DIFFERENCE

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | $F$ |
|---|---|---|---|---|
| Between parallelism deviations ($P$) | Fixed | 2 | 1.4919 | 6.32[a] |
| Between mediums ($M$) | Random | 2 | 0.2040 | 1.00 |
| Between speeds ($S$) | Fixed | 2 | 1.2737 | 3.53 |
| $P$ x $M$ interaction | -- | 4 | 0.2359 | 1.16 |
| $M$ x $S$ interaction | -- | 4 | 0.3604 | 1.77 |
| $P$ x $S$ interaction | -- | 4 | 0.0937 | 0.46 |
| Residual error | -- | 8 | 0.2034 | |

[a]Significant at the 0.10 level.

## Average Flute Height

The variance analysis in Table XLIV indicates that for the conditions of this study, deviations from roll parallelism had no significant effect on flute height. There were indications that an interaction between parallelism and medium existed; therefore, with some mediums, small differences in flute height might be encountered due to deviations in roll parallelism.

TABLE XLIV

ANALYSIS OF THE EFFECT OF ROLL PARALLELISM
ON AVERAGE FLUTE HEIGHT

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | $\underline{F}$ |
|---|---|---|---|---|
| Between parallelism deviations ($\underline{P}$) | Fixed | 2 | 0.0411 | 0.08 |
| Between mediums ($\underline{M}$) | Random | 2 | 10.4544 | 114.05[b] |
| Between speeds ($\underline{S}$) | Fixed | 2 | 0.6878 | 1.10 |
| $\underline{P}$ x $\underline{M}$ interaction | -- | 4 | 0.4856 | 5.30[a] |
| $\underline{M}$ x $\underline{S}$ interaction | -- | 4 | 0.6272 | 6.84[a] |
| $\underline{P}$ x $\underline{S}$ interaction | -- | 4 | 0.1022 | 1.12 |
| Residual error | -- | 8 | 0.0917 | |

[a]Significant at the 0.05 level.
[b]Significant at the 0.01 level.

## EFFECT OF ANGLE OF TAKE-OFF

In the past, careful observation of the single-faced board as it emerges from the pressure roll nip has suggested that any tendency toward high-low flute formation may be accentuated if the newly formed adhesive bond is stressed sufficiently to permit movement of the medium at the adhesive interface. At this stage the newly formed bond is believed to be quite weak. Consequently, if the tips of the fluted medium are pressed sideways by the tips of the upper corrugating roll, the stress may be transmitted to the bond causing a small movement or slippage of the medium relative to the liner. Such "slippage" may accentuate high-low flute formation.

In general, the possibility of interference between corrugating roll and single-faced board will depend on the angle of take-off of the single-faced board from the pressure roll nip. If the angle of take-off is low — i.e., the board follows the pressure roll circumference for some distance — there is less chance of interference and presumably, less possibility that high-low flute formation will be accentuated. The reverse may occur if the angle of take-off is high — i.e., the board follows the corrugating roll circumference for some distance. Limited experimental measurements in the past have tended to support this hypothesis (42).

To study the effect of angle take-off on high-low flute formation for this study, three mediums were evaluated using three angles of take-off — namely, 15° low, tangential, and 15° high. The results obtained are summarized in Table XLV. On the average, slightly lower caliper differences were obtained with the 15° low take-off angle as would be expected on the basis of past work. The average caliper differences for the 15° high take-off angle were, however, no higher than were obtained with the tangential take-off angle.

Average Caliper Difference

To analyze the statistical significance of the changes, the results at speeds of 300, 450, and 600 ft./min. for each medium were selected for analysis inasmuch as results were available at all three speeds for each medium. These data are summarized in Table XLVI and the variance table is shown in Table XLVII. The overall average caliper differences (from Table XLVI) for the three conditions were as follows:

| Take-Off Angle | Av. Caliper Diff., pt. |
|---|---|
| 15° low | 2.50 |
| Tangential | 2.91 |
| 15° high | 2.75 |

TABLE XLV

EFFECT OF ANGLE OF TAKE-OFF ON HIGH-LOW CORRUGATIONS

| Medium Identification | | | Corr. | Single-Face Caliper, pt. | | | Individual Flute Caliper | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Av. Caliper, pt. | | | Av. Diff., pt. | | | Max. Diff., pt. | | | Cumulative Percentage of Differences in Flute Height, % | | | | | | | | |
| | | | | | | | | | | | | | | | | 0 - 3.0 pt. | | | 0 - 4.0 pt. | | | 0 - 5.0 pt. | | |
| | | Roll | Speed, | Angle of Take-Off | | | Angle of Take-Off | | | Angle of Take-Off | | | Angle of Take-Off | | | Angle of Take-Off | | | Angle of Take-Off | | | Angle of Take-Off | | |
| No. | Type[a] | No. | ft./min. | 15° Low | Tangential | 15° High | 15° Low | Tangential | 15° High | 15° Low | Tangential | 15° High | 15° Low | Tangential | 15° High | 15° Low | Tangential | 15° High | 15° Low | Tangential | 15° High | 15° Low | Tangential | 15° High |
| 1 | 26-Lb. S.C. | 30 | 150 | 192.3 | -- | 191.8 | 194.4 | -- | 193.8 | 1.56 | -- | 1.27 | 5.3 | -- | 3.1 | 85.0 | -- | 97.5 | 92.5 | -- | 100.0 | 97.5 | -- | 100.0 |
| | | | 300 | 192.2 | 192.2 | 192.2 | 194.5 | 194.2 | 193.9 | 2.13 | 1.98 | 1.72 | 6.0 | 6.1 | 5.0 | 72.5 | 77.5 | 80.0 | 90.0 | 92.5 | 92.5 | 92.5 | 95.0 | 100.0 |
| | | | 450 | 192.4 | 192.0 | 191.7 | 194.3 | 194.1 | 194.0 | 2.05 | 2.71 | 2.08 | 6.5 | 7.1 | 6.5 | 75.0 | 67.5 | 80.0 | 97.5 | 77.5 | 87.5 | 97.5 | 80.0 | 95.0 |
| | | | 600 | 192.3 | 191.9 | 191.7 | 194.2 | 194.1 | 194.1 | 3.11 | 3.54 | 3.39 | 8.2 | 8.4 | 6.7 | 47.5 | 52.5 | 42.5 | 67.5 | 62.5 | 65.0 | 85.0 | 75.0 | 75.0 |
| | | | 700 | -- | 192.0 | -- | -- | 194.2 | -- | -- | 3.40 | -- | -- | 10.0 | -- | -- | 57.5 | -- | -- | 65.0 | -- | -- | 75.0 | -- |
| | | | Av. | 192.3 | 192.0 | 191.8 | 194.4 | 194.2 | 194.0 | 2.21 | 2.91 | 2.12 | | | | | | | | | | | | |
| 4 | 26-Lb. K | 146 | 300 | 192.7 | 193.1 | 193.2 | 195.0 | 195.4 | 195.4 | 2.83 | 2.51 | 3.34 | 7.3 | 7.2 | 6.8 | 55.0 | 65.0 | 42.5 | 70.0 | 80.0 | 70.0 | 82.5 | 90.0 | 90.0 |
| | | | 450 | 192.9 | 193.1 | 193.0 | 195.1 | 195.3 | 195.2 | 2.66 | 3.32 | 2.63 | 6.2 | 8.0 | 7.0 | 57.5 | 55.0 | 70.0 | 87.5 | 72.5 | 80.0 | 95.0 | 77.5 | 82.5 |
| | | | 600 | 192.3 | 193.2 | 193.3 | 194.8 | 195.8 | 195.4 | 2.94 | 3.49 | 3.88 | 9.5 | 9.4 | 9.3 | 67.5 | 55.0 | 50.0 | 72.5 | 67.5 | 52.5 | 80.0 | 80.0 | 60.0 |
| | | | 850 | 191.0 | -- | -- | 193.0 | -- | -- | 6.08 | -- | -- | 18.0 | -- | -- | 37.5 | -- | -- | 40.0 | -- | -- | 45.0 | -- | -- |
| | | | 900 | -- | 192.2 | 192.4 | -- | 194.0 | 193.5 | -- | 3.69 | 6.82 | -- | 15.2 | 15.0 | -- | 62.5 | 30.0 | -- | 67.5 | 35.0 | -- | 80.0 | 40.0 |
| | | | Av. | 192.2 | 192.9 | 193.0 | 194.5 | 195.1 | 194.9 | 3.63 | 3.25 | 4.17 | | | | | | | | | | | | |
| 6 | 26-Lb. B | 90 | 300 | 191.4 | 192.3 | 190.8 | 193.7 | 193.9 | 192.9 | 1.67 | 3.03 | 2.62 | 6.0 | 8.4 | 7.0 | 77.5 | 57.5 | 62.5 | 87.5 | 65.0 | 77.5 | 95.0 | 77.5 | 90.0 |
| | | | 450 | 190.6 | 190.2 | 189.8 | 192.1 | 192.2 | 191.6 | 2.72 | 2.59 | 2.76 | 6.8 | 5.4 | 7.5 | 57.5 | 52.5 | 62.5 | 77.5 | 80.0 | 77.5 | 95.0 | 90.0 | 85.0 |
| | | | 600 | 190.4 | 189.9 | 189.5 | 192.3 | 191.9 | 191.3 | 2.41 | 3.01 | 2.34 | 6.1 | 8.6 | 7.1 | 67.5 | 60.0 | 75.0 | 77.5 | 75.0 | 87.5 | 87.5 | 80.0 | 87.5 |
| | | | 825 | -- | -- | 188.9 | -- | -- | 191.1 | -- | -- | 4.07 | -- | -- | 10.7 | -- | -- | 50.0 | -- | -- | 65.0 | -- | -- | 67.5 |
| | | | 900 | 189.2 | 189.0 | -- | 191.4 | 191.3 | -- | 3.34 | 3.89 | -- | 9.7 | 11.5 | -- | 52.5 | 50.0 | -- | 72.5 | 65.0 | -- | 82.5 | 75.0 | -- |
| | | | Av. | 190.4 | 190.4 | 189.8 | 192.4 | 192.3 | 191.7 | 2.54 | 3.13 | 2.95 | | | | | | | | | | | | |
| Composite average: | | | | 191.6 | 191.8 | 191.5 | 193.8 | 193.9 | 193.5 | 2.79 | 3.10 | 3.08 | | | | | | | | | | | | |

[a]S.C. = semichemical; K = kraft; B = bogus.

TABLE XLVI

SUMMARY OF DATA USED IN STATISTICAL ANALYSES OF THE EFFECT OF ANGLE OF TAKE-OFF ON HIGH-LOW CORRUGATIONS

| Medium No. | Speed, ft./min. | Average Caliper, pt. Angle of Take-Off 15° Low | Tangential | 15° High | Composite | Average Caliper Diff., pt. Angle of Take-Off 15° Low | Tangential | 15° High | Composite |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 300 | 194.5 | 194.2 | 193.9 | | 2.13 | 1.98 | 1.72 | |
| | 450 | 194.3 | 194.1 | 194.0 | 194.2 | 2.05 | 2.71 | 2.08 | 2.52 |
| | 600 | 194.2 | 194.1 | 194.1 | | 3.11 | 3.54 | 3.39 | |
| | Av. | 194.3 | 194.1 | 194.0 | | 2.43 | 2.74 | 2.40 | |
| 4 | 300 | 195.0 | 195.4 | 195.4 | | 2.83 | 2.51 | 3.34 | |
| | 450 | 195.1 | 195.3 | 195.2 | 195.3 | 2.66 | 3.32 | 2.63 | 3.07 |
| | 600 | 194.8 | 195.8 | 195.4 | | 2.94 | 3.49 | 3.88 | |
| | Av. | 195.0 | 195.5 | 195.3 | | 2.81 | 3.11 | 3.28 | |
| 6 | 300 | 193.7 | 193.9 | 192.9 | | 1.67 | 3.00 | 2.62 | |
| | 450 | 192.1 | 192.2 | 191.6 | 192.4 | 2.72 | 2.59 | 2.76 | 2.57 |
| | 600 | 192.3 | 191.9 | 191.3 | | 2.41 | 3.01 | 2.34 | |
| | Av. | 192.7 | 192.7 | 191.9 | | 2.27 | 2.88 | 2.57 | |
| Average: | 300 | 194.4 | 194.5 | 194.1 | 194.3 | 2.21 | 2.51 | 2.56 | 2.43 |
| | 450 | 193.8 | 193.9 | 193.6 | 193.8 | 2.48 | 2.87 | 2.49 | 2.61 |
| | 600 | 193.8 | 193.9 | 193.6 | 193.8 | 2.82 | 3.35 | 3.20 | 3.12 |
| Composite av.: | | 194.0 | 194.1 | 193.8 | | 2.50 | 2.91 | 2.75 | |

While slightly lower caliper differences were obtained with the 15° low take-off angle as expected, the greatest caliper difference was obtained with the tangential take-off instead of the 15° high take-off angle. The analysis of variance indicated the differences between angles were not statistically significant at the 0.05 level. Because of variability in high-low measurements and the limited number of medium samples involved, the analysis was apparently not sensitive enough to distinguish between effects in this case. In this connection it may be noted that the 95% confidence interval for the above composite averages is ± 0.33 point. As a result the confidence limits on the composite averages are rather broad and the effect of any change must be relatively large to be statistically significant.

TABLE XLVII

ANALYSIS OF THE EFFECT OF ANGLE OF TAKE-OFF
ON THE AVERAGE CALIPER DIFFERENCE

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | $F$ |
|---|---|---|---|---|
| Between take-off angles ($A$) | Fixed | 2 | 0.3783 | 4.15 |
| Between mediums ($M$) | Random | 2 | 0.8131 | 4.36[a] |
| Between speeds ($S$) | Fixed | 2 | 1.1734 | 2.96 |
| $A$ x $M$ interaction | -- | 4 | 0.0910 | 0.49 |
| $M$ x $S$ interaction | -- | 4 | 0.3963 | 2.12 |
| $A$ x $S$ interaction | -- | 4 | 0.0515 | 0.28 |
| Residual error | -- | 8 | 0.1867 | |

[a]Significant at the 0.10 level.

Average Flute Height

The results of a similar analysis of the effect of take-off angle on flute height are summarized in Table XLVIII. As may be noted, the angle of take-off, by itself, had no statistically significant effect on flute height. A significant interaction between take-off angle and medium was obtained; however, inspection of Table XLVI suggests that the effect was relatively small and may not be of practical interest.

TABLE XLVIII

ANALYSIS OF THE EFFECT OF ANGLE TAKE-OFF
ON AVERAGE FLUTE HEIGHT

| Source of Variance | Factor Classification | Degrees of Freedom | Mean Square | F |
|---|---|---|---|---|
| Between take-off angles (A) | Fixed | 2 | 0.2826 | 0.96 |
| Between mediums (M) | Random | 2 | 18.3426 | 406.88[b] |
| Between speeds (S) | Fixed | 2 | 0.9259 | 1.11 |
| A x M interaction | -- | 4 | 0.2943 | 6.53[a] |
| M x S interaction | -- | 4 | 0.8326 | 18.47[b] |
| A x S interaction | -- | 4 | 0.0093 | 0.21 |
| Residual error | -- | 8 | 0.0451 | |

[a]Significant at the 0.05 level.
[b]Significant at the 0.01 level.

EFFECT OF WEB ORIENTATION

To determine if the orientation of the web as it enters the corrugating nip affects high-low corrugations, each of three mediums were fabricated in two ways, namely, (1) wire side down, wire side bonded to single-face liner, and (2) wire side up, felt side bonded to single-face liner. The results obtained are shown in Table XLIX. On the average, changes in web orientation appeared to have little or no effect on either flute height or the average caliper difference. This was confirmed by an analysis of variance which indicated the small differences observed were not statistically significant.

## EFFECT OF MOISTURE CONTENT

As mentioned previously, three rolls of semichemical medium were supplied to the Institute by one manufacturer with moisture contents of 1.7, 4.3, and 20.0% (ovendry). These rolls were fabricated into single-faced board for the purpose of determining the effects of moisture content on high-low corrugations. In addition, a series of fabrication runs were made to study the effects of nonuniform moisture content on high-low corrugations. For this purpose "wet streaks" were simulated by applying a moistened sponge at periodic intervals to the medium before the preheater and caliper measurements were then made on both wetted and unwetted areas of the single-faced board.

The results obtained are summarized in Table L. Considering first the case where the moisture content may be considered to be more or less uniformly distributed throughout the roll, it may be noted that two fabrication trials were made on each roll at a number of speeds inasmuch as the "control" in the "wet streak" phase is essentially a replicate of the "nonwet streak" runs. The data for the duplicate runs are shown in Table LI and Fig. 21. As may be noted, differences in roll moisture content had little or no effect on the average caliper difference. In contrast, increasing roll moisture content tended to markedly decrease flute height. Therefore, for these materials and experimental conditions it appears that roll moisture content may be varied over a wide range (so long as it is reasonably uniform) without materially affecting the tendency to form high-low corrugations though lower flute heights may be obtained at high moisture contents.

TABLE XLIX

EFFECT OF WEB ORIENTATION ON HIGH-LOW CORRUGATIONS

| Medium Identification | | | Corr. | Single-Face Caliper, pt. | | Individual Flute Caliper | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Av. Caliper, pt. | | Av. Diff., pt. | | Max. Diff., pt. | | Cumulative Percentage of Differences in Flute Height, % | | | | | |
| | | | | | | | | | | | | 0 - 3.0 pt. | | 0 - 4.0 pt. | | 0 - 5.0 pt. | |
| No. | Type[a] | Roll No. | Speed, ft./min. | Wire Side Up | Wire Side Down | Wire Side Up | Wire Side Down | Wire Side Up | Wire Side Down | Wire Side Up | Wire Side Down | Wire Side Up | Wire Side Down | Wire Side Up | Wire Side Down | Wire Side Up | Wire Side Down |
| 1 | 26-Lb. S.C. | 29 | 300 | 191.4 | 191.2 | 194.2 | 194.0 | 1.37 | 1.60 | 5.7 | 4.8 | 85.0 | 85.0 | 90.0 | 97.5 | 97.5 | 100.0 |
| | | | 450 | 190.9 | 190.6 | 194.3 | 193.9 | 2.77 | 2.38 | 7.3 | 6.5 | 55.0 | 70.0 | 75.0 | 75.0 | 92.5 | 85.0 |
| | | | 600 | 190.7 | 190.4 | 194.1 | 193.9 | 1.90 | 2.47 | 6.2 | 6.5 | 80.0 | 72.5 | 90.0 | 80.0 | 95.0 | 92.5 |
| | | | 625 | 190.8 | -- | 194.1 | -- | 3.48 | -- | 9.7 | -- | 55.0 | -- | 72.5 | -- | 77.5 | -- |
| | | | 750 | -- | 190.4 | -- | 194.2 | -- | 2.74 | -- | 7.4 | -- | 50.0 | -- | 70.0 | -- | 90.0 |
| | | | Av. | 191.0 | 190.6 | 194.2 | 194.0 | 2.38 | 2.30 | | | | | | | | |
| 3 | 26-Lb. K | 145 | 150 | 190.8 | -- | 193.8 | -- | 3.31 | -- | 8.5 | -- | 52.5 | -- | 72.5 | -- | 77.5 | -- |
| | | | 300 | 191.3 | 191.8 | 194.2 | 195.5 | 4.20 | 2.94 | 9.7 | 10.0 | 40.0 | 62.5 | 50.0 | 75.0 | 55.0 | 82.5 |
| | | | 325 | 191.9 | -- | 194.9 | -- | 3.20 | -- | 8.0 | -- | 50.0 | -- | 60.0 | -- | 85.0 | -- |
| | | | 350 | 188.5 | -- | 194.0 | -- | 3.84 | -- | 8.0 | -- | 40.0 | -- | 50.0 | -- | 67.5 | -- |
| | | | 450 | -- | 191.0 | -- | 194.4 | -- | 3.67 | -- | 7.0 | -- | 42.5 | -- | 57.5 | -- | 67.5 |
| | | | 525 | -- | 191.6 | -- | 195.2 | -- | 3.62 | -- | 8.5 | -- | 52.5 | -- | 60.0 | -- | 67.5 |
| | | | 575 | -- | 190.3 | -- | 195.1 | -- | 3.17 | -- | 10.9 | -- | 57.5 | -- | 67.5 | -- | 75.0 |
| | | | Av. | 190.6 | 191.2 | 194.2 | 195.0 | 3.64 | 3.35 | | | | | | | | |
| 5 | 26-Lb. B | 85 | 300 | 191.6 | 192.2 | 194.0 | 194.4 | 1.74 | 1.07 | 4.7 | 2.4 | 82.5 | 100.0 | 97.5 | 100.0 | 100.0 | 100.0 |
| | | | 450 | 191.7 | 190.8 | 193.5 | 193.5 | 1.47 | 2.04 | 3.1 | 5.8 | 97.5 | 72.5 | 100.0 | 87.5 | 100.0 | 92.5 |
| | | | 600 | 191.5 | 192.7 | 193.7 | 194.7 | 1.89 | 2.14 | 4.7 | 6.1 | 80.0 | 80.0 | 90.0 | 92.5 | 100.0 | 95.0 |
| | | | 1000 | 191.4 | 191.5 | 193.7 | 194.0 | 2.58 | 3.26 | 7.6 | 9.2 | 70.0 | 50.0 | 77.5 | 70.0 | 87.5 | 82.5 |
| | | | Av. | 191.6 | 191.8 | 193.7 | 194.2 | 1.92 | 2.13 | | | | | | | | |
| | Composite average: | | | 191.1 | 191.2 | 194.0 | 194.4 | 2.65 | 2.59 | | | | | | | | |

[a] S.C. = semichemical; K = kraft; B = bogus.

Note: When the wire side was down, the wire side was bonded to the single-face liner and vice versa.

TABLE L

EFFECT OF MOISTURE CONTENT ON HIGH LOW CORRUGATIONS

(26-lb. Semichemical medium)

| Corr. Speed, ft./min. | Wet Streak Added[a] | Single-Face Caliper, pt. | | | Individual Flute Caliper: Av. Caliper, pt. | | | Av. Diff., pt. | | | Max. Diff., pt. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Moisture Content, % | | | Moisture Content, % | | | Moisture Content, % | | | Moisture Content, % | | |
| | | 1.7[b] | 4.3[c] | 20.0[d] | 1.7[b] | 4.3[c] | 20.0[d] | 1.7[b] | 4.3[c] | 20.0[d] | 1.7[b] | 4.3[c] | 20.0[d] |
| **Effect of Roll Moisture Content** | | | | | | | | | | | | | |
| 150 | None | 192.8 | -- | 196.3 | 196.3 | -- | 193.0 | 1.38 | -- | 1.40 | 4.0 | -- | 5.2 |
| 300 | " | 193.6 | 193.6 | 197.3 | 197.3 | 196.1 | 192.3 | 1.83 | 1.71 | 1.69 | 5.0 | 5.9 | 4.5 |
| 450 | " | 194.1 | 193.2 | 198.8 | 198.8 | 196.0 | 191.1 | 2.61 | 3.02 | 2.94 | 6.5 | 7.6 | 6.8 |
| 600 | " | -- | 192.8 | -- | -- | 196.3 | 189.3 | -- | 3.18 | 3.76 | -- | 7.9 | 9.7 |
| 725 | " | -- | 193.6 | -- | -- | 197.2 | -- | -- | 5.10 | -- | -- | 11.2 | -- |
| **Effect of Added Wet Streak** | | | | | | | | | | | | | |
| 150 | None (Control) | 192.8 | 192.6 | 187.9 | 196.3 | 195.2 | 189.1 | 1.72 | 1.38 | 1.36 | 4.5 | 5.2 | 7.8 |
| | Yes | 187.5 | 188.3 | 181.5 | 189.1 | 189.8 | 183.4 | 4.00 | 3.68 | 1.96 | 9.5 | 10.4 | 5.5 |
| 300 | None (Control) | 193.6 | 192.6 | 187.7 | 198.6 | 196.0 | 189.2 | 2.64 | 2.82 | 2.42 | 6.4 | 7.1 | 9.1 |
| | Yes | 189.9 | 188.9 | 182.4 | 191.7 | 190.7 | 184.0 | 3.28 | 4.80 | 3.34 | 8.3 | 10.7 | 11.4 |
| 450 | None (Control) | 193.8 | 192.5 | 186.8 | 199.8 | 195.7 | 188.3 | 3.13 | 2.56 | 2.97 | 11.3 | 8.2 | 9.0 |
| | Yes | 190.7 | 189.2 | 182.8 | 192.6 | 190.6 | 184.2 | 3.44 | 4.76 | 2.64 | 12.0 | 12.5 | 9.0 |
| 600 | None (Control) | -- | 191.6 | -- | -- | 194.7 | -- | -- | 4.11 | -- | -- | 12.0 | -- |
| | Yes | -- | 188.5 | -- | -- | 190.4 | -- | -- | 4.86 | -- | -- | 13.4 | -- |
| Average | None (Control) | 193.4 | 192.3 | 187.5 | 198.2 | 195.4 | 188.9 | 2.50 | 2.72 | 2.25 | -- | -- | -- |
| | Yes | 189.4 | 188.7 | 182.2 | 191.1 | 190.4 | 183.9 | 3.57 | 4.52 | 2.65 | -- | -- | -- |

[a] Wet streak added before preheater with wet sponges.

[b] Medium sample 8, roll 175.

[c] Medium sample 9, roll 173.

[d] Medium sample 10, roll 174.

TABLE LI

EFFECT OF "UNIFORM" MOISTURE CONTENT ON FLUTE HEIGHT
AND AVERAGE CALIPER DIFFERENCES

| Speed, ft./min. | Trial[a] | Av. Caliper, pt. Moisture Content, % 1.7 | 4.3 | 20.0 | Av. Diff., pt. Moisture Content, % 1.7 | 4.3 | 20.0 |
|---|---|---|---|---|---|---|---|
| 150 | 1 | 196.3 | -- | 193.0 | 1.38 | -- | 1.40 |
| | 2 | 196.3 | 195.2 | 189.1 | 1.72 | 1.38 | 1.36 |
| | Av. | 196.3 | -- | 191.0 | 1.55 | -- | 1.38 |
| 300 | 1 | 197.3 | 196.1 | 192.3 | 1.83 | 1.71 | 1.69 |
| | 2 | 198.6 | 196.0 | 189.2 | 2.64 | 2.82 | 2.42 |
| | Av. | 198.0 | 196.0 | 190.8 | 2.24 | 2.26 | 2.06 |
| 450 | 1 | 198.8 | 196.0 | 191.1 | 2.61 | 3.02 | 2.94 |
| | 2 | 199.8 | 195.7 | 188.3 | 3.13 | 2.56 | 2.97 |
| | Av. | 199.3 | 195.8 | 189.7 | 2.87 | 2.79 | 2.96 |
| Composite av.: | | 197.8 | 195.8 | 190.5 | 2.22 | 2.30 | 2.13 |

[a]Trial 1 results are from the roll moisture content phase and Trial 2 results are the control runs from the wet streak phase.

In the literature review, it was noted that a number of investigators stressed the importance of proper moisture content with regard to high-low corrugations. For example, Velarde (43) indicated high-low corrugations were a minimum when the medium has a moisture content of 6 to 7.5%. Also, the respondents to the questionnaire distributed by Scordas (35) agreed that increasing the moisture content of the medium reduced the frequency of high-low corrugations. It is evident that the results obtained in this limited comparison are not in agreement with the results reported in the literature and, therefore, should be treated with caution.

In contrast with the above, it may be noted in Table L or Fig. 22 that "nonuniform" moisture content substantially increased, in most cases, the average caliper differences in the "wetted" areas and lowered the flute height. While the wetting technique used herein is admittedly a drastic technique, it nonetheless suggests that wet streaks may be expected to increase the tendency toward high-low corrugations.

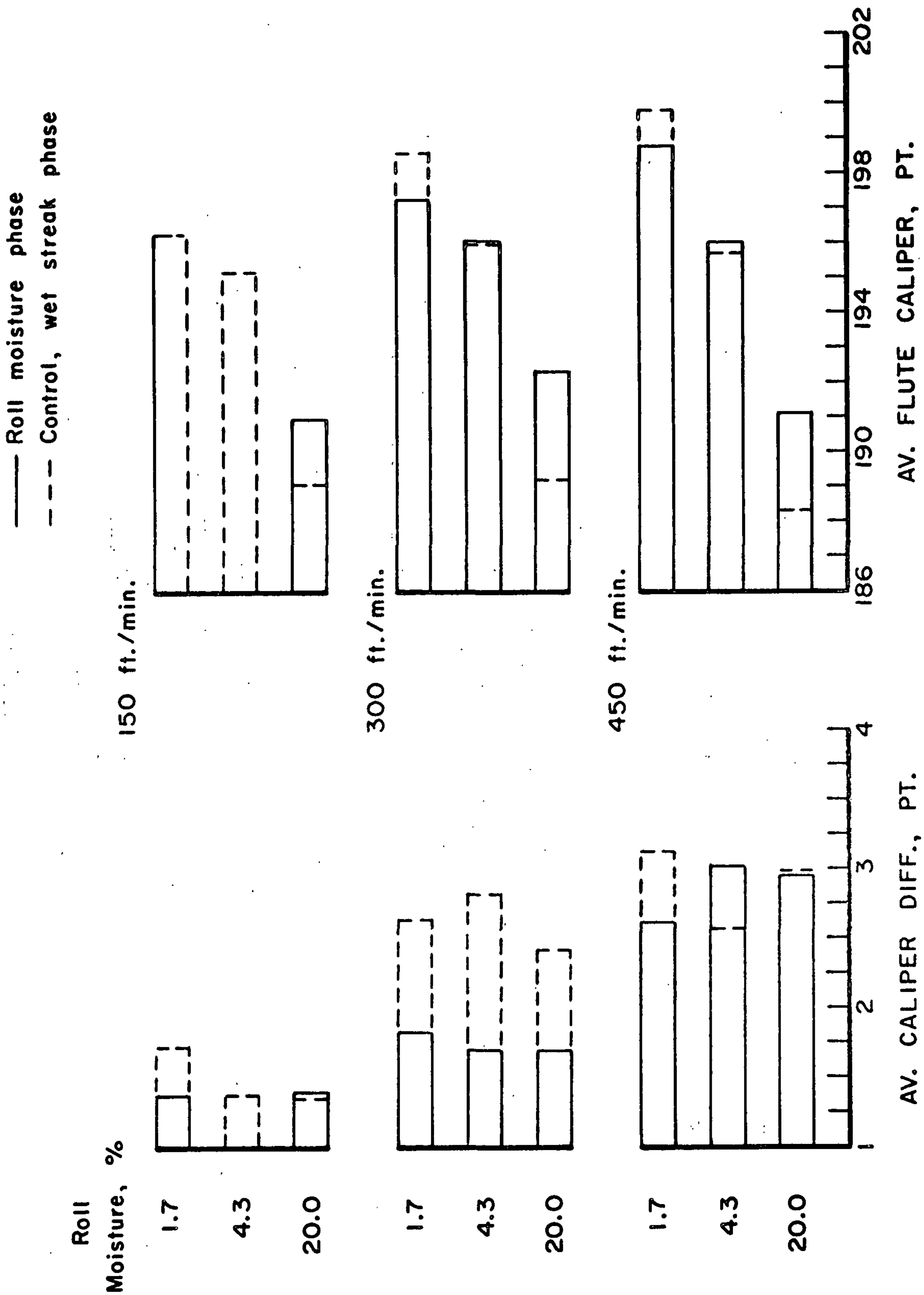


Figure 21. Effect of Uniform Moisture Content on High-Low Corrugations

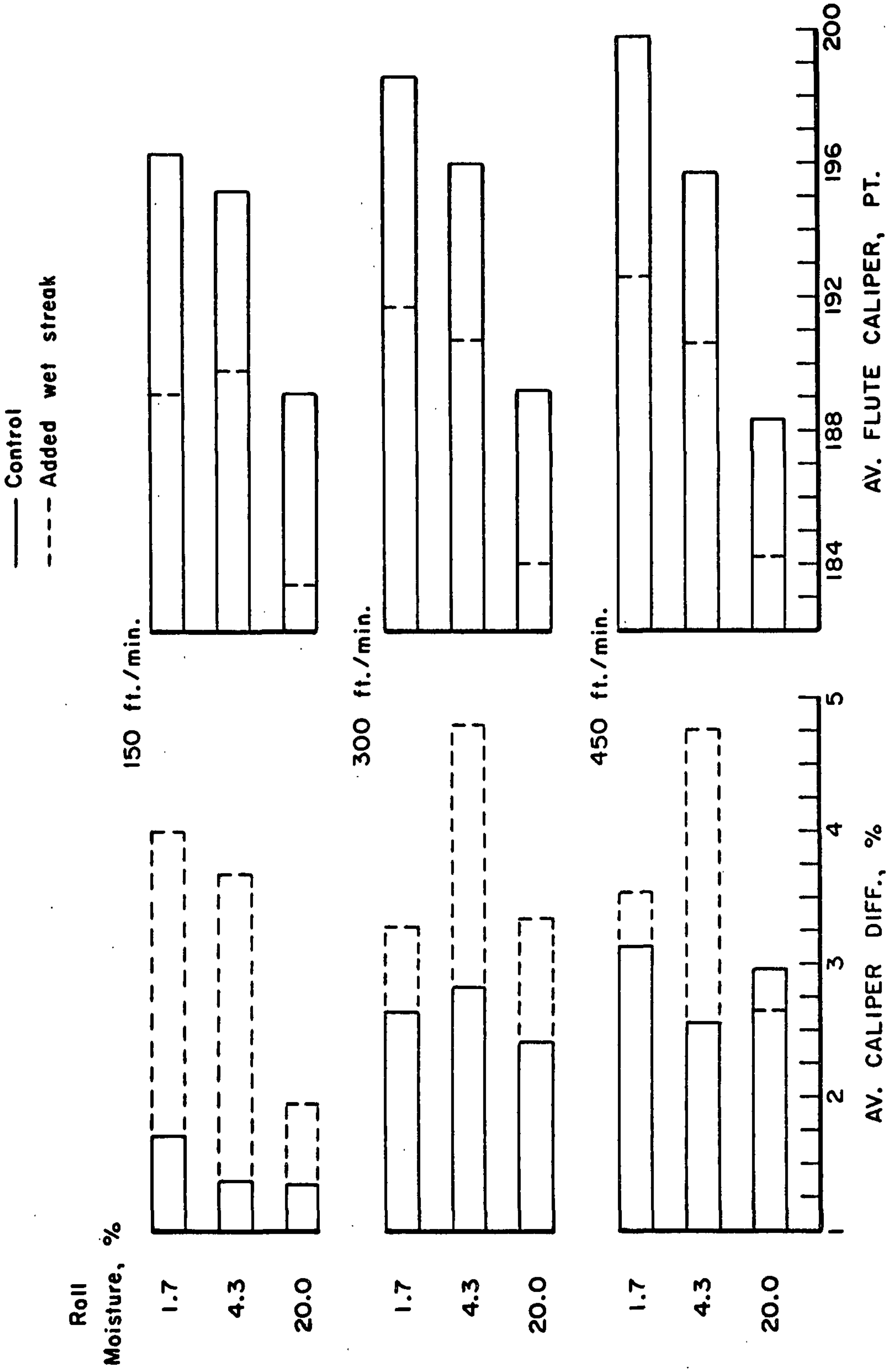


Figure 22. Effect of "Nonuniform" Moisture Content on High-Low Corrugations

An analysis of variance was also carried out using the data in Table LI at speeds of 300 and 400 ft./min. for the average caliper difference. This results in a three factor problem in which the main factors are: 1) moisture content, 2) speed, and 3) trials. For the analysis, the individual caliper difference observations were utilized. In this connection, it should be kept in mind that the caliper difference (difference in height of consecutive flutes) does not give a normal bell-shaped distribution. Because the sign of the difference is disregarded, the shape of the distribution must be skewed. While the analysis of the variance technique is not particularly sensitive to departures from normality, the fact that the underlying distributions are skewed may affect the stated probabilities in the following discussion to some extent.

The results of the analysis are summarized in Table LII. In the analysis, moisture content and speed were considered to be fixed factors, whereas trial was considered to be a random factor. A random factor is one in which the particular levels chosen are considered to be a random sample of a large number of levels that might have been chosen. Thus, in this application, the two trials were considered to be a random sample out of the large number that could have been made assuming sufficient material. Further discussion of the difference between fixed and random factors may be found in Reference (44).

As may be noted, neither moisture content nor speed exhibited a significant $\underline{F}$ ratio for these rather limited data. Only two significant effects were obtained. First, a significant difference (0.01 level) between trials was obtained and second, the speed x trial interaction was significant at the 0.05 level. Both are indicative that significant differences in high-lows can be obtained even in repeat trials on material from a single roll.

TABLE LII

ANALYSIS OF VARIANCE OF MOISTURE CONTENT RESULTS

(Uniform moisture content phase)

| Source of Variance | Degrees of Freedom | Mean Square | F | Components of Variance |
|---|---|---|---|---|
| Between moisture contents (M) | 2 | 0.0884 | 0.66 | $\sigma_o^2 + 80\,\sigma_{MT}^2 + 160\,\sigma_M^2$ |
| Between speeds (S) | 1 | 56.6501 | 2.57 | $\sigma_o^2 + 120\,\sigma_{ST}^2 + 240\,\sigma_S^2$ |
| Between trials (T) | 1 | 24.7976 | 7.29[b] | $\sigma_o^2 + 240\,\sigma_T^2$ |
| M x S interaction | 2 | 1.4706 | 0.35 | $\sigma_o^2 + 40\,\sigma_{MST}^2 + 80\,\sigma_{MS}^2$ |
| S x T interaction | 1 | 22.0591 | 6.49[a] | $\sigma_o^2 + 120\,\sigma_{ST}^2$ |
| M x T interaction | 2 | 1.3344 | 0.39 | $\sigma_o^2 + 80\,\sigma_{MT}^2$ |
| M x S x T interaction | 2 | 4.2327 | 1.24 | $\sigma_o^2 + 40\,\sigma_{MTS}^2$ |
| Residual | 468 | 3.4013 | -- | $\sigma^2$ |

[a]Significant at the 0.05 level.

[b]Significant at the 0.01 level.

Note: F tests made as indicated by components of variance; e.g., between moisture contents mean square is divided by mean square for M x T interaction.

The nature of the speed x trial interaction is shown in Table LIII where the caliper differences have been averaged for the three moisture content levels involved.

TABLE LIII

EFFECT OF SPEED AS EVALUATED IN THE TWO TRIALS

| | Av. Caliper Diff., pt. | | |
|---|---|---|---|
| | Trial 1 | Trial 2 | Av. |
| 300 ft./min. | 1.74 | 2.63 | 2.18 |
| 450 ft./min. | 2.86 | 2.89 | 2.87 |
| Average | 2.30 | 2.76 | 2.52 |

In Trial 1 an appreciable difference was obtained at the two speeds, whereas in Trial 2 the caliper differences at the two speeds were more nearly alike. This implies that in a given run rather substantial differences in the average caliper difference can be obtained at two (or more) speeds which may or may not be confirmed in a duplicate run. This probably reflects variations in medium quality within a roll and in the corrugator conditions and helps to explain some of the variations in caliper difference from speed-to-speed which were noted in earlier phases of this study.

The fact that a significant difference existed between trials is also of importance. This also probably reflects variations in medium quality within a roll and in corrugator conditions. It certainly suggests that the high-low tendencies observed in a single corrugator run should be viewed with caution.

Keeping in mind the nonnormal nature of the caliper difference distribution, it may be noted that the square root of the residual variance ($\sigma_o^2$) corresponds to the standard deviation of the individual caliper difference observations. In this instance, it equals 1.84 pt. or expressed as a percentage of the overall average (coefficient of variation) is equal to about 73%. When it is recalled that the coefficients of variation of most strength properties of paperboard are usually less than 15 to 20%, it may be seen that the caliper difference has an unusually large coefficient of variation. This indicates that the precision of the average difference will be low (wide confidence limits) unless a relatively large number of measurements is made. In addition, it suggests that the nature of the caliper difference distribution should be studied in more detail. Techniques for "normalization" of the distribution might be helpful. Also, it should be kept in mind that high-low corrugations at the double-backer are, in general, formed from the larger differences in flute height — i.e., from the "tail" of the distribution. As a result, the arithmetic average caliper difference may, in some cases, rather inadequately characterize the "tail" of the distribution.

The between trial variance ($\sigma_{\underline{T}}^2$), based on these results, is equal to 0.089 pt. and the trial x speed interaction ($\sigma_{\underline{TS}}^2$) variance is equal to 0.156 pt. The corresponding standard deviations are 0.30 and 0.39 pt. and the coefficients of variation are 12 and 16%, respectively. While considerably lower than the coefficient of variation of the individual observations, they indicate that replication of runs will increase precision.

As an illustration, consider the case where it is desired to compare the high-low tendencies of several types of medium when fabricated at some selected speed. In designing the experiment, decisions must be made with regard to the number of individual caliper differences to be measured and the possible desirability of also making duplicate runs. In general, the objective is to select a sampling scheme which will result in adequate precision for the various medium averages while maintaining test costs (including fabrication charges) at a minimum. For this case, neglecting the speed x trial interaction, the standard error (S.E.) of the average caliper difference for a given medium would be as follows:

$$S.E. = (\sigma_o^2/N_r N_t) + \sigma_T^2/N_t$$

where $\sigma_o^2$ = variance of individual observations

$\sigma_T^2$ = between trial variance

$N_r$ = number of individual observations

$N_t$ = number of repeat runs

The 95% confidence intervals are then obtained by multiplying the standard error by the appropriate value of $t$ (a value of 1.96 was used in the following calculations).

Using the above expression, various sampling schemes are compared in Table LIV in terms of the resulting confidence interval. The following comments may be made:

1. Increasing $N_r$ (number of individual observations) gives lower confidence limits; however, the point of diminishing returns appears to be reached between 40 and 80 observations. [Note: 40 observations were made in this study.]

2. Making duplicate runs results in a fairly substantial lowering of the confidence interval at any selected value of $N_r$. Further increases in $N_t$ (at constant $N_r$) lower the confidence interval but at a slower rate. Because fabrication trials are believed to be more costly than the individual flute measurements, it would be desirable, perhaps, to restrict the possible values of $N_t$ to either 1 or 2.

3. None of the plans result in very low confidence intervals. It is quite likely that any of the plans where $N_r$ is greater than 80 or $N_t$ is greater than 2 would be too costly; therefore, while lower confidence intervals could be achieved by further increases in $N_r$ or $N_t$, the plans would probably be impractical.

TABLE LIV

COMPARISON OF SAMPLING PLANS IN TERMS OF 95% CONFIDENCE LIMITS

| No. of Individual Difference Observations ($N_r$) | No. of Fabrication Trials ($N_t$) | Standard Error, pt. | 95% Confidence Limits Points | Percent[a] |
|---|---|---|---|---|
| 20 | 1 | 0.51 | ± 1.00 | ± 40 |
| | 2 | 0.36 | ± 0.71 | ± 28 |
| | 3 | 0.29 | ± 0.57 | ± 23 |
| | 4 | 0.25 | ± 0.49 | ± 19 |
| 40 | 1 | 0.42 | ± 0.82 | ± 33 |
| | 2 | 0.30 | ± 0.59 | ± 23 |
| | 3 | 0.24 | ± 0.47 | ± 19 |
| | 4 | 0.21 | ± 0.41 | ± 16 |
| 80 | 1 | 0.36 | ± 0.71 | ± 28 |
| | 2 | 0.26 | ± 0.51 | ± 20 |
| | 3 | 0.21 | ± 0.41 | ± 16 |
| | 4 | 0.18 | ± 0.35 | ± 14 |
| 160 | 1 | 0.33 | ± 0.65 | ± 26 |
| | 2 | 0.23 | ± 0.45 | ± 18 |
| | 3 | 0.19 | ± 0.37 | ± 15 |
| | 4 | 0.17 | ± 0.33 | ± 13 |

[a]Percent of average value (2.52 pt.).

4. For an equal number of individual observations, it may be noted that there is some advantage in reducing $\underline{N}_r$ and increasing $\underline{N}_t$. For example, when comparing the case where $\underline{N}_r = 20$, $\underline{N}_t = 2$ with $\underline{N}_r = 40$, $\underline{N}_t = 1$, the lower confidence interval is obtained when $\underline{N}_r = 20$, $\underline{N}_t = 2$. The gain is not great — from $\pm$ 33 to $\pm$ 28%, but it is present. In this instance, the number of individual tests are equal; however, the two fabrication trials required when $\underline{N}_r = 20$, $\underline{N}_t = 2$ would make it more expensive than the alternate plan $\underline{N}_r = 40$, $\underline{N}_t = 1$. The increase in cost in this case would have to be balanced against the gain in precision.

In general, the selection of a plan will depend on the desired precision level and consideration of the costs involved. In this particular example, the high variability of the caliper differences makes it difficult to achieve low confidence intervals (high precision) without going to rather costly plans. It should be kept in mind that much depends on the accuracy of the estimates of the variances involved. Because these data are derived from a very limited study, the estimates of the between-trial variance may be subject to considerable uncertainty. However, the analysis does suggest that efforts to relate high-lows to the physical characteristics of the medium may be hampered by the high variabilities involved in high-low measurement.

## EFFECT OF MEDIUM PROPERTIES

In general, high-low corrugations are a manifestation of the fact that the heights of consecutive flutes vary in a periodic manner — i.e., the heights are, in general, alternately high and low. The height periodicity appears to be present in all corrugated board regardless of medium used though the magnitude may differ from medium to medium. Even a material such as aluminum foil which has markedly different properties than corrugating medium exhibits the same type of periodic pattern in flute height though the differences in height may be small.

The fact that the phenomenon is invariably encountered regardless of material indicates that the basic cause is inherent in the process and is a machine effect though the magnitude may be influenced by the medium. Exactly what machine factors cause the periodic high-low variations is not definitely known. Machine variables which may be involved are (1) "jumping" or "drop" action of the upper corrugating roll, (2) dynamic variations in web tension and/or radial molding force, and (3) cyclic variations in the rotational acceleration of the corrugating rolls, etc. For example, if the dynamic variations in maximum web tension are studied, periodic patterns apparently resembling the high-low pattern can, at times, be seen though, whether such variations are the cause of high-lows or are, instead, caused by some other factor is not well understood.

With regard to the properties of the medium which affect high-lows, it may be speculated that those properties involved in medium runnability may also be involved in the tendency to form high-low corrugations. This appears possible because high-lows generally become more pronounced as the fracture is approached. However, even though the same properties may be involved in both runnability and high-lows, it is quite likely that their relative importance may be quite different.

Because this study was directed toward evaluating the effects of various operational variables on high-low corrugations, there are insufficient data to permit more than a limited comparison of runnability with the physical characteristics of the medium. For this purpose the average caliper differences of the 26-lb. mediums were averaged over the four following phases of the study: (1) web tension, (2) steam showers, (3) amount of preheat, and (4) roll pressure. The data are shown in Table LV. This procedure has the advantage of averaging out variations in high-lows from run-to-run or roll-to-roll.

TABLE LV

AVERAGE CALIPER DIFFERENCES AND FLUTE HEIGHT FOR 26-LB. MEDIUMS

| Medium | Web Tension, lb./in. | | | Shower Pressure, p.s.i. | | | Preheater Wrap | | | Roll Pressure, lb./in. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 0.25 | 1 | 2 | 0 | 14 | 28 | None | Half | Full | 187 | 327 | 513 | Average |
| | | | | | | Av. Caliper Diff., pt. | | | | | | | |
| 1 | 2.40 | 2.49 | 1.52 | 2.45 | 2.19 | 2.06 | 2.34 | 3.14 | 2.38 | 3.47 | 2.38 | 2.17 | 2.42 |
| 2 | 3.54 | 3.92 | 3.44 | 3.72 | 3.92 | 3.46 | 3.10 | 3.86 | 3.04 | 5.40 | 3.04 | 2.94 | 3.62 |
| 3 | 2.92 | 3.45 | 2.73 | 4.67 | 3.30 | 3.81 | 3.93 | 4.14 | 3.64 | 3.54 | 3.64 | 3.72 | 3.62 |
| 4 | 2.76 | 3.27 | 3.74 | 4.09 | 3.27 | 2.22 | 3.40 | 3.78 | 3.30 | 5.61 | 3.30 | 3.63 | 3.53 |
| 5 | 2.45 | 1.92 | 1.84 | 2.32 | 1.92 | 1.91 | 2.02 | 2.22 | 2.67 | 2.47 | 2.67 | 1.86 | 2.19 |
| 6 | 3.03 | 2.68 | 3.01 | 3.58 | 2.68 | 2.82 | 3.02 | 2.54 | 3.01 | 2.66 | 3.01 | 3.29 | 2.94 |
| | | | | | | Av. Flute Caliper, pt. | | | | | | | |
| 1 | 196.0 | 194.4 | 193.6 | 195.6 | 194.0 | 193.6 | 192.6 | 193.9 | 194.2 | 193.0 | 194.2 | 195.0 | 194.2 |
| 2 | 194.8 | 194.2 | 193.1 | 194.5 | 194.2 | 193.6 | 193.0 | 193.8 | 194.3 | 192.5 | 194.3 | 194.4 | 193.9 |
| 3 | 194.1 | 193.6 | 193.0 | 194.8 | 194.2 | 193.7 | 192.8 | 194.0 | 194.2 | 193.1 | 194.2 | 194.9 | 193.9 |
| 4 | 197.8 | 196.2 | 196.3 | 198.1 | 196.2 | 196.9 | 195.1 | 195.9 | 195.5 | 193.4 | 195.5 | 196.7 | 196.1 |
| 5 | 195.2 | 193.7 | 193.4 | 196.1 | 193.7 | 194.0 | 192.8 | 194.0 | 194.0 | 193.2 | 194.0 | 195.0 | 194.1 |
| 6 | 194.0 | 192.8 | 192.0 | 195.0 | 192.8 | 192.2 | 190.4 | 191.8 | 192.4 | 191.1 | 192.4 | 193.4 | 192.5 |

The average caliper differences are graphically compared with a number of the medium characteristics in Fig. 23 and 24. As may be noted, none of the properties taken individually is well related to high-low corrugations.

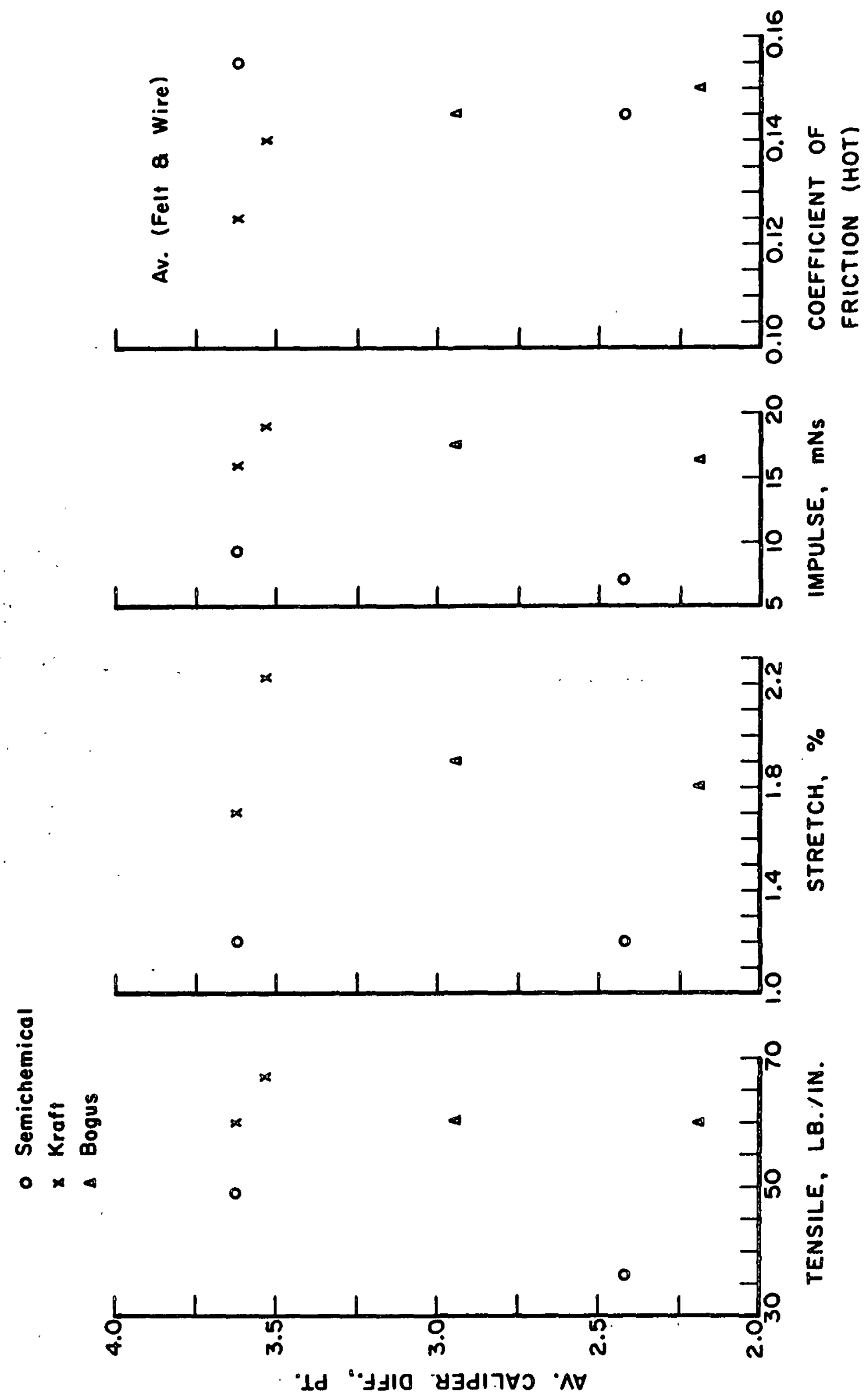


Figure 23. Relationship Between the Average Caliper Difference and Various Properties of the Corrugating Medium

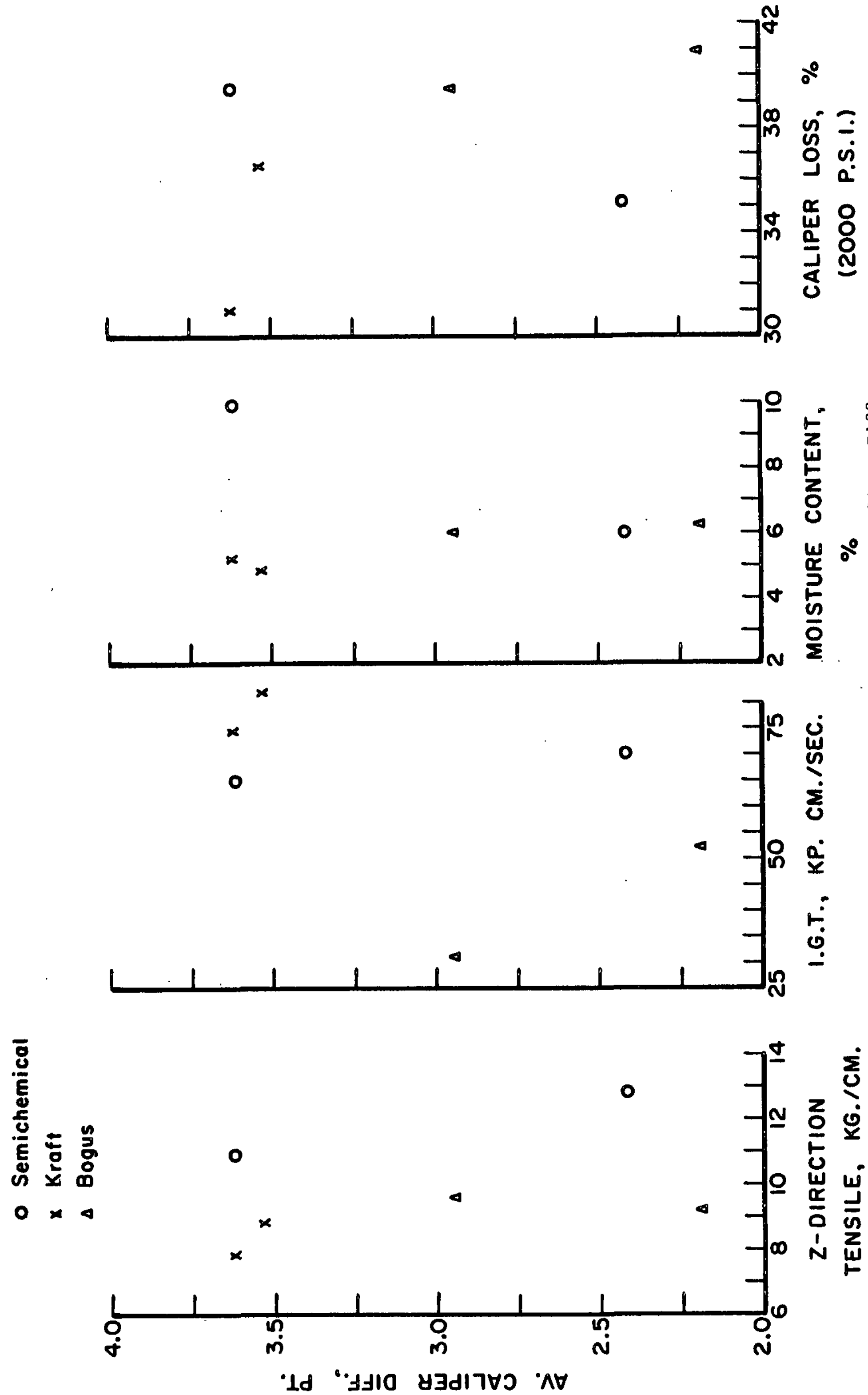


Figure 24. Relationship Between the Average Caliper Difference and Various Properties of the Corrugating Medium

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